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WIRELESS SOLUTIONS

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Understanding Antenna Specifications and Operation

contributed by Linx Technologies

The antenna is probably the most overlooked part of an RF design. The field of antenna design and application is complex. By understanding a few ground rules it is not necessary to be an antenna designer to design with an antenna.

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Is Minnesota Really That Cold in Winter?

Have you ever wondered if winter temperatures in Minnesota really dip to negative 30 degrees Fahrenheit? Now you can find out by tracking Digi-Key's Weather Center without having to experience the bitter cold yourself.

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Editorial Comment

Mark Zack
Director, Semiconductor

M2M communication is exploding in all industries and demographics; consumers have come to expect little or no service/equipment disruptions or spotty connectivity. Regulatory changes are driving adoption in many regions and countries including the European Union, Brazil and China. *ABI Research* estimates that the WWAN M2M Module market will increase over 200% to 114 million units shipped by 2015. M2M designers are challenged by complex design cycles and strict regulatory approvals. Given the inherent design challenges and strong end customer demand for wireless solutions, the timing is perfect for this issue of *TechZone™* magazine on M2M communications.

In this issue, we delve into all facets of M2M communications and how to overcome typical technical roadblocks. You will find a great selection of articles that will support your M2M design decisions including:

- "Understanding Antenna Specifications and Operation" – an interesting article about real world **antenna performance** contributed by Linx Technologies (page 10)
- "Optimizing Security Sensor Battery Life" – an article on combining **low-power wireless** protocol with a **low-power processor** contributed by Ember Corporation (page 26)
- "Merging Legacy Systems and the Smart Grid" – an article on adding secure and **reliable two-way communications** by Dave Mayne from Digi International (page 38)

We've expanded our supplier base in recent months to include Dresden Elektronic (Atmel-based ZigBee 802.15.4 modules and kits), Laird Technologies (antennas), and Taoglas (embedded and external M2M antennas). Digi-Key represents over 100 industry-leading manufacturers of wireless products. Our expansive range of products will support your entire M2M communications design and production needs.

Worldwide demand is accelerating in the M2M space with a clear movement toward real time communication and endless applications extending way beyond automotive. We believe that the information and insights in this issue of *TechZone™* magazine will support your next generation product ideas and solutions.

Sincerely,

Mark Zack
Director, Semiconductor
Digi-Key Corporation

About Digi-Key Corporation

As one of the world's fastest growing distributors of electronic components, Digi-Key Corporation has earned its reputation as an industry leader through its total commitment to service and performance. As a full-service provider of both prototype/design and production quantities of electronic components, Digi-Key has been ranked #1 for Overall Performance for 18 consecutive years from among the nation's more than 200 distributors (EE Times Distribution Study/August 2009). Offering more than 1.7 million products from more than 440 quality name-brand manufacturers, Digi-Key's commitment to inventory is unparalleled. Access to the company's broad product offering is available 24/7 at Digi-Key's top-rated website.

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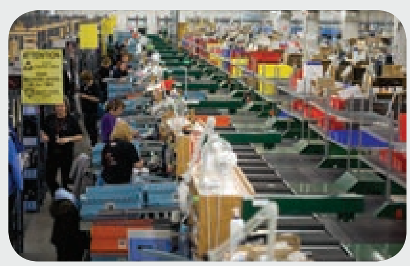

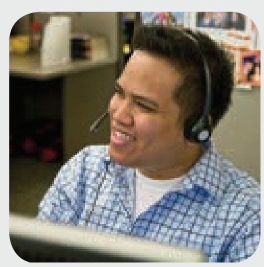

Wireless TechZone℠ Q & A

In the rapidly evolving wireless market, it seems as if there is something new every day – technologies, products, consumer trends, or regulations. Time-to-market demands have never been greater with the design of many of today's new wireless products requiring expertise in more than one discipline.

You have questions. We have answers. On target to field more than 260,000 calls this year, our technical support specialists are available 24/7/365 to answer your questions and assist you with your wireless needs.

If you have a question, we invite you to contact our technical staff via telephone, live web chat, or by emailing your question to techzone@digikey.com.

What network topologies are supported by ZigBee?

There are three different network topologies that are supported by ZigBee, namely the star, mesh and cluster tree or hybrid networks. Each has its own advantages and can be used to advantage in different situations. The star network is commonly used, having the advantage of simplicity. As the name suggests it is formed in a star configuration with outlying nodes communicating with a central node. Mesh or peer-to-peer networks enable high degrees of reliability. They consist of a variety of nodes placed as needed, and nodes within range being able to communicate with each other to form a mesh. Messages may be routed across the network using the different stations as relays. There is usually a choice of routes that can be used and this makes the network very robust. If interference is present on one section of a network, then another route can be used instead. Finally there is what is known as a cluster tree network. This is a combination of star and mesh topologies.

For RFID, do all countries use the same low-, high- and ultra-high frequencies?

Most countries have assigned the 125 kHz or 134 kHz area of the radio spectrum for low-frequency systems with 13.56 MHz being used around the world for high-frequency systems. However, UHF RFID systems have only been around since the mid-1990s and countries have not agreed on a single area of the UHF spectrum for RFID. Europe uses 868 MHz for UHF while the U.S. uses 915 MHz. Until recently, Japan did not allow any use of the UHF spectrum for RFID. In 2003, they opened up the 950 to 956 MHz band for RFID. Many other devices use the UHF spectrum, so it will take years for all governments to agree on a single UHF band for RFID. Governments also regulate the power of the RFID readers to limit interference with other devices. Some groups, such as the Global Commerce Initiative, are trying to encourage governments to agree on frequencies and output. Tag and reader makers are also trying to develop systems that can work at more than one frequency, to get around the problem.

Will using Wi-Fi and Bluetooth technologies together cause interference?

Studies by a number of companies indicate that if the separation is more than two meters, in most cases there is no perceptible degradation in transmitted data in either device. From two meters to about a half-meter, there is a graceful degradation. As the devices are brought into very close proximity, the degradation can be quite noticeable. Fortunately, this scenario only happens when the two systems are in the same device, and in those cases, Bluetooth hardware and Wi-Fi hardware can collaborate to dramatically improve performance.

Is there a need for a central controller in a Z-Wave lighting system?

No, and this is a major value of a mesh network. Other lighting control systems that have been on the market for a while have relied on a centralized lighting cabinet. All lighting circuits require wires that lead back to this cabinet, and all control functions (scenes, zones, intensity) are controlled inside this cabinet. Operation of the system is determined by use of wall-mounted switches, dimmer and controllers. However, everything is hard wired back to one control cabinet. Z-Wave eliminates the centralized cabinet requirement, thus dramatically lowering the costs, by allowing each device to become an intelligent transceiver: sending and receiving command information wirelessly. Putting all these individual intelligent devices into a home makes the entire system more reliable, efficient and scaleable. It also allows the products to be used in retrofit and new home construction with equal results.

Do you have a question about wireless solutions?

Digi-Key has more than 130 technical support specialists, product managers, and applications engineers who are eager to answer your questions and assist you with your wireless projects.

Send your questions to **techzone@digikey.com**.

Achieving RF Performance and Approvals

by Dermot O'Shea, *Taoglas*

Antenna design may seem to be as much art as science, but by following a few simple design rules you can reliably hit your performance and approval targets.

Before selecting the antenna or antenna design and defining the mechanical specifications for a wireless product the product designer must clearly understand the RF performance targets the product must reach in order to:

- Achieve good RF performance in the field to ensure market success
- Pass all regulatory and operator approvals.

Performance

The Basic concepts – TRP, TIS, and RSE

For cellular applications such as GSM or CDMA, basic RF performance is measured in terms of the product being able to transmit and receive reliably on a network. The scientific way to measure performance is in an anechoic chamber.

The measurements numbers used are outlined below:

- **TRP – Total Radiated Power**
  This defines how much power is being radiated from the device and is measured in dBm. The higher this number, the better the device is able to transmit.
- **TIS – Total Isotropic Sensitivity**
  This defines how low a signal the device can receive and demodulate. The lower this number (with a minus figure) the better the device can operate in weak signal environments.
- **RSE – Radiated Spurious Emissions.**
  In practice this is the most difficult test for cellular products to pass, from Taoglas' experience. These are radio waves output by the device which are above the power limit set by regulatory authorities to avoid interference. When a test confirms a radiated spurious emission over the limit either the device or the antenna must be modified to get it below the limit and thus pass certification. Otherwise the device cannot be sold in that country.

Different operators, especially in the USA (such as AT&T, Sprint, etc.) have specific numbers for TRP and TIS that the device must reach to be accepted on their networks. Other operators do not specifically set any requirements. No matter if it is mandatory or not, it is our experience that the wireless products with the best TRP and TIS values succeed in the market. Passing RSE is mandatory for any operator whom requires PTCRB or type approvals. A design that has optimized TRP/TIS will usually pass RSE on the first attempt.

Wireless products are regulated in each country by slightly different standards. Taoglas, in co-operation with certified test labs, can advise on the exact regulations a product must conform to and provide a test plan.

In Table 1 are targets to reach for passing most but not all operator TRP/TIS approvals. Some operators have specific targets for certain products or applications so you need to confirm individually. In any case these are the numbers any designer should target for their device.

Table 1: TRP and TIS performance targets (all figures in dBm).

	Maximum Conducted Power	TRP	Maximum Conducted Sensitivity	TIS
GSM 850	33	22	-109	-99
GSM 900	33	23	-109	-100
GSM 1800	30	24	-109	-101
GSM 1900	30	24.5	-109	-101
UMTS/HSPA/ HSPA+/WCDMA 850	23	13	-109	-97
UMTS/HSPA/ HSPA+/WCDMA 1700	23	18.5	-109	-101
UMTS/HSPA/ HSPA+/WCDMA 1900	23	18.5	-109	-101
UMTS/HSPA/ HSPA+/WCDMA 2100	23	18.5	-109	-101

If your operator does not have a stated standard, or their standard is not mandatory, it is advisable to aim for these, or higher, numbers in order to accomplish the best industry standard.

Your product can in many cases still function normally below these values, there is no industry set cut-off for operation. It will depend on the actual application environment and your own conditions for what is acceptable in terms of reliability and the outcome of your own product field tests.

How are these **TRP** and **TIS** numbers calculated?

TRP

For TRP we have to work backwards from the maximum power allowed from a RF module. For most cellular modules this is capped by the FCC at 33 dBm for GSM 850 and 30 dBm for GSM 1900.

Let's take a specific example. Usually the module will be set at a slightly lower power rating than maximum allowed. This would mean at GSM 850 with a power level of 32 dBm, this leaves us 10 dB of loss in the device to still pass the 22 dBm target. This sounds like plenty of margin but there are a lot of losses in the system.

As the RF signal passes down a cable or a transmission line on the device board it easily loses 4 dB or more. 4 dB loss is **more than half the loss** of the original power coming from the module.

- When the signal reaches the antenna and is radiated out into the air, it will also inevitably lose more.
- So 32 dBm – 4 dB = 28 dBm, meaning we need to reduce the loss from the antenna side to -6 dB or less.
- This -6 dB loss is equivalent to saying the antenna has an average gain of -6 dB.
- Therefore we need to design an antenna that has better than average gain of -6 dB for the device to reach the TRP performance required.

TIS
For TIS, a similar calculation can be done. For example, knowing that a network operator for GSM 850 has set a signal strength of greater than -99 dBm, we can work backwards to what losses are allowed in the device for the device to still operate on the network.

The majority of cellular module sensitivity is around -109 dBM, therefore the device can sustain another 10 dB in loss on the antenna and transmission lines/cable and still reach the operator requirements.

- This means in theory again we can budget for -4 dB loss for example in the transmission line (could be less or more).
- It leaves us -6 dB in loss for the antenna.
- This is equivalent to the antenna average gain of -6 dB which is usually possible for the antenna designer to do.

However, **in real life** TIS is most affected by noise on the board. In many cases this noise will totally overpower the underlying GSM signal. This noise must either be removed from the system, or the antenna placed far enough away from it not to pick it up. Of course either way is very difficult to achieve when the design is complete.

What can Taoglas do to help?
Designing an optimized RF device depends on many parameters, both electrical and mechanical. Fortunately, Taoglas can utilize our experienced engineers, unparalleled range of antennas, and real industry experience to come out with a solid reliable process to enable a customer's product to succeed.

Antenna type, layout, and design

Below are some simple rules to follow for the mechanical dimensions of a product which can pass the strictest operator TRP/TIS requirements. I am sure you are asking yourself - how come I used mobile phones that clearly violate these guidelines? Firstly they may not have targeted the above figures for device efficiency but if you look closely, most mobile phones do adhere to the guidelines below. Certain operators negotiate directly with mobile phone companies on lower TRP/TIS standards on their device on a case by case basis. These options are unlikely to be available to M2M devices.

(A) Ground planes < 65 mm long
For a ground plane with a length of less than 65 mm (and 40 mm wide) the only solution is a complete custom antenna. The type of antenna material and design will vary from device to device and the process should begin at the start of the product design process.

(B) Ground planes > 65 mm long

(i) On-board Antenna Solutions - minimum width needs to be 40 mm.

PA-25a Ceramic Antenna
- Cleared area needs to be all the way across the short side of the board.
- From module side to antenna it requires 10 mm clearance to metal.
- Other sides must be completely free of metal.

Figure 1: PA-25a Ceramic Antenna.

Custom Metal PIFA Antenna
- Can work directly on ground plane on center edge of PCB minimum height of elements 10 mm, length 60 mm, and width 25 mm.
- Clearance to other metal components ideally 20 mm or greater in all directions.

Figure 2: Custom Metal PIFA Antenna.

(ii) Off-board Antenna Solutions – Ground plane width of the device needs to be greater than 20 mm.

A proven example is 80 mm x 40 mm of ground plane and 20 mm of clearance from antenna to metal, but in theory the ground plane of the device can be smaller.

Flexible circuit antenna – FXP14
- Can be mounted to the inner plastic housing of the device.
- Minimum clearance of 20 mm from metal in all directions.
- Mount at right angles (perpendicular) to any main-board.
- Cable should be shorter than 150 mm, but not less than 80 mm.
- Place antenna away from noise/activity sources.

Figure 3: Flexible circuit antenna – FXP14.

PIFA on housing

- Dimensions approximately 60 mm x 20 mm x 10 mm.
- 20 mm clearance to metal.
- Spring contact can be used for connection.

Figure 4: PIFA on housing.

Rigid PCB FR4 Antenna – PC.30

- Can be mounted to the inner plastic housing of the device.
- Minimum clearance of 20 mm from metal in all directions.
- Mount at right angles (perpendicular) to any main-board.
- Cable should be shorter than 150 mm, but not less than 80 mm.
- Place antenna away from noise/activity sources.

Figure 5: Rigid PCB FR4 Antenna – PC.30.

PTCRB

For cellular wireless products sold in the USA, Canada, and other regions, it is necessary to apply for PTCRB approval from the CTIA wireless association.

A designated lab will test your product to establish if it meets the requirements.

PTCRB itself does not set minimum pass/fail standards for TRP/TIS, but there is a strict RSE standard - higher than the traditional FCC test standard. So you can actually pass RSE and get PTCRB even with compromised device performance (if TRP and TIS are not considered).

Individual operators may specify their own TRP/TIS test standards and even more tests before they will accept your device on their network. Taoglas can assist wireless device designers in meeting these approvals first time around.

Disclaimer: RF design is inherently difficult. Taoglas provides this article as a reference only and cannot be held responsible for errors or omissions in this information or for the performance of devices that use this above information. Users are advised to discuss with a Taoglas representative for a formal solution proposal before proceeding on any design.

ATmega128RFA1 Wireless MCU

Atmel

Atmel's ATmega128RFA1 Wireless MCU is the world's first wireless AVR and consists of a unique Atmel microcontroller and RF transceiver. The device is designed for industrial and consumer IEEE 802.15.4, ZigBee, 6LoWPAN, RF4CE, and high data rate 2.4 GHz ISM brand applications.

This product training module reviews the power specifications and data encryption offered with the series, covers the data rates and onboard Hardware Accelerator, and provides specific application examples.

The module is 28 pages long and can be viewed with or without audio in twenty minutes.

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Did You Know?

In addition to the measurement of the radio parameters, Electromagnetic Compatibility (EMC) (using the EN 301 489 series of standards) and Safety (per the EN/IEC 60950 and EN 61010 standards) are also mandatory requirements for most radio devices deployed are the globe.

Understanding Antenna Specifications and Operation

contributed by Linx Technologies

The antenna is one of the most complicated aspects of RF design, and specifications on an antenna's data sheet will not necessarily reflect its performance in the final product. Understanding how antennas work in the real world will help to dispel much of the mystery.

The antenna is probably the most overlooked part of an RF design. The range, performance, and legality of an RF link are critically dependent upon the antenna. However, it is often left until the end of the design and expected to fit into whatever space is left, no matter how unfavorable to performance that location may be. Many of these designs will have to ultimately accept degraded performance or go through multiple redesigns.

With so many interdependent variables, antenna design becomes as much art as science. Engineers delving into RF design for the first time can easily confuse or misinterpret the meaning of antenna specifications and how to apply them. For instance, the gain of an antenna is very different from the gain of an amplifier. The most common misconception may be that the radiation pattern on a monopole antenna's data sheet will be that of the antenna on the final product. In actuality, the radiation pattern for a quarter-wave monopole antenna is so critically dependant on the design and layout of the product, that manufacturers' gain specifications and radiation pattern plots have little use except to ascertain potential antenna performance.

Since voluminous texts have been written about each of the many antenna styles, it is unnecessary to cover them all here. This article will focus only on those styles which are commonly used in low-power handheld products: dipole and monopole whips. These styles cover a wide range of available antennas and are among the most common to be implemented incorrectly. With that in mind, there are several rules-of-thumb that can be applied to antenna designs. These rules are less "how to design an antenna" and more "how to design *with* an antenna."

Antenna fundamentals

An antenna is a device that converts electric currents into electromagnetic waves and vice versa. It can be considered a complex RLC network. At some frequencies, it will appear as an inductive reactance, at others as a capacitive reactance. At a specific frequency, both of the reactances will be equal in magnitude, but opposite in influence, and thus cancel each other. At this specific frequency, the impedance is purely resistive and the antenna is said to be resonant.

Here is where the physical meets the theoretical. Resonance will occur at whole number multiples or fractions of the frequency of interest. These frequencies correspond to a wavelength. That wavelength is the required antenna length. That length is what must be incorporated into the final product, either embedded inside the enclosure or externally attached to the device.

The frequency of the electromagnetic waves is related to the wavelength by the following equation:

$$\lambda = \frac{c}{f}$$

where

f = frequency in Hertz (Hz)

λ = wavelength in meters (m)

c = speed of light (299,792,458 m/s)

As can be seen by the equation, the higher the frequency, the shorter the wavelength, and the smaller the antenna. For example, the wavelength for 433.92 MHz is 0.69 m (2.27 ft.) and the wavelength for 916 MHz is 0.33 m (1.07 ft.). 433.92 MHz is a popular frequency for Remote Keyless Entry (RKE) systems such as car key fobs, but obviously there is no way that a 2.27 foot antenna is going to fit into a key fob.

Fortunately for everyone who wants to carry their keys in their pocket, there are ways to make the antenna smaller. Since resonance will occur at whole number fractions (1/2, 1/3, 1/4, etc.) of the fundamental frequency, shorter antennas can be used to send and recover the signal. As with everything in engineering, there is a trade-off. Reducing the antenna's size will have some impact on the efficiency and impedance of the antenna, which can affect the final performance of the system.

A half-wave dipole antenna has a length that is one-half of the fundamental wavelength. It is broken into two quarter-wave lengths called elements. The elements are set at 180 degrees from each other and fed from the middle. This type of antenna is called a center-fed half-wave dipole and shortens the antenna length by half.

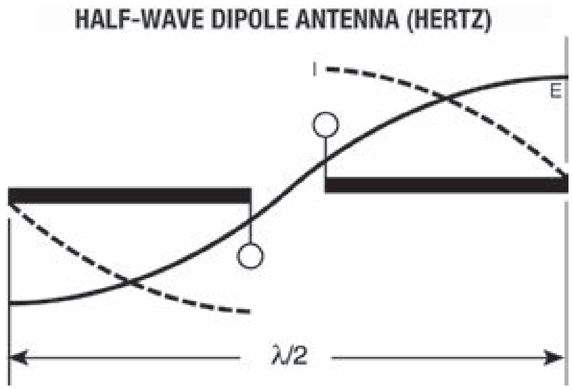


Figure 1: A Half-Wave Dipole Antenna.

A method for making the antenna even smaller is to use one of the quarter-wave elements of a dipole and allow the ground plane on the product's PCB to serve as a counterpoise, in essence, creating the other quarter-wave element.

Since most devices have a circuit board anyway, using it for half of the antenna can make a lot of sense. Generally, this half of the antenna will be connected to ground and the transmitter or receiver will reference it accordingly. This style is called a quarter-wave monopole and is the most common antenna in today's portable devices.

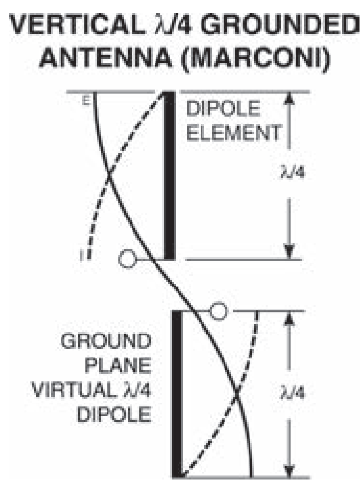


Figure 2: A Quarter-Wave Monopole Antenna.

Figure 3: 916 MHz (L) and 315 MHz (R) Helical Antennas.

Another way to reduce the size of the antenna is to coil the element. This is where the straight wire is coiled or wrapped around a non-conductive substrate to create what is called a helical element. This has the advantage of making the overall length shorter, but it will also reduce the antenna's bandwidth. Like an inductor, the tighter the coil and the higher the Q, the smaller the bandwidth. Where a straight antenna may have a bandwidth of 100 MHz, a helical may only have a bandwidth of 10 MHz. This becomes more pronounced as the frequency gets lower, since the coils typically get closer together to maintain a specific overall length.

Antenna specifications

If antennas are the least understood RF component, then antenna specifications are the least understood of all RF components. For instance, many designers look for radiated test data without really understanding what they are looking at or how it relates to the performance of their product. For this reason, let's examine the most common antenna specifications.

Impedance

The impedance of an antenna is the real resistance and imaginary reactance that appears at the terminals of the antenna. Because there are inductive and capacitive elements to an antenna, this will change with frequency. It will also be affected by objects that are nearby, such as other antennas, the components on a circuit board and even the user of the device.

An antenna will have two types of resistance associated with it. Radiation resistance converts electrical power into radiation. Ohmic resistance is loss on the antenna's structure that converts electrical power into heat. The radiation resistance should be much higher than the ohmic resistance, though both are important to the antenna's efficiency. Generally, the radiation resistance at the terminals of a dipole antenna in free space (isolated from anything conductive) is 73 ohms. A monopole antenna will be half of this, or 36.5 ohms.

The reactance is power that is stored in the near field of the antenna. This reactance combined with the real resistance make up the antenna's impedance. Both values are affected by objects in the near field and will vary down the antenna's length. The specifics of this are beyond the scope of this article, but can be found in most antenna literature.

These values are important because, in any system, maximum power transfer will occur when the source and load impedances match. If they are different, called a mismatch, then some of the power sent to the antenna will be reflected back into the load or lost as heat. This will lower the efficiency of the system, lowering range, increasing power requirements and shortening battery life.

Industry convention for RF is an impedance of 50 ohms. Most IC manufacturers will have matched their products to 50 ohms or will provide a circuit designed to match their product to a 50 ohm load. Likewise, antenna manufacturers frequently design and characterized antennas at 50 ohms.

VSWR

The Voltage Standing Wave Ratio (VSWR) is a measurement of how well an antenna is matched to a source impedance, typically 50 ohms. It is calculated by measuring the voltage wave that is headed toward the load versus the voltage wave that is reflected back from the load. A perfect match will have a VSWR of 1:1, however the higher the first number, the worse the match, the more inefficient the system. Since a perfect match cannot ever be obtained, some benchmark for performance needs to be set. In the case of antenna VSWR, this is usually 2:1. At this point, 88.9 percent of the energy sent to the antenna by the transmitter is radiated into free space and 11.1 percent is either reflected back into the source or lost as heat on the structure of the antenna. In the other direction, 88.9 percent of the energy recovered by the antenna is transferred into the receiver. As a side note, since the ":1" is always implied, many data sheets will remove it and just display the first number.

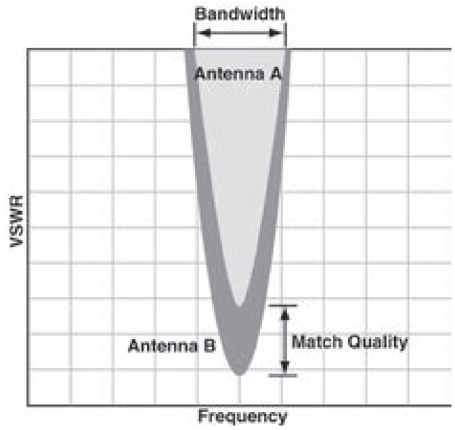


Figure 4: VSWR Graph.

VSWR is usually displayed graphically versus frequency, as shown in Figure 4. The lowest point on the graph is the antenna's center frequency. The VSWR at that point denotes how close the antenna gets to 50 ohms. The space between the points where the graph crosses the specified VSWR typically defines the antenna's bandwidth.

Directivity, efficiency, and gain

True antenna performance can only be determined by measuring the amount of energy that the antenna radiates into free space. This is not an easy task given all of the variables associated with radiated measurements. When the radiated power is measured around the antenna, a shape emerges called the radiation pattern. This is the most direct measurement of an antenna's actual performance.

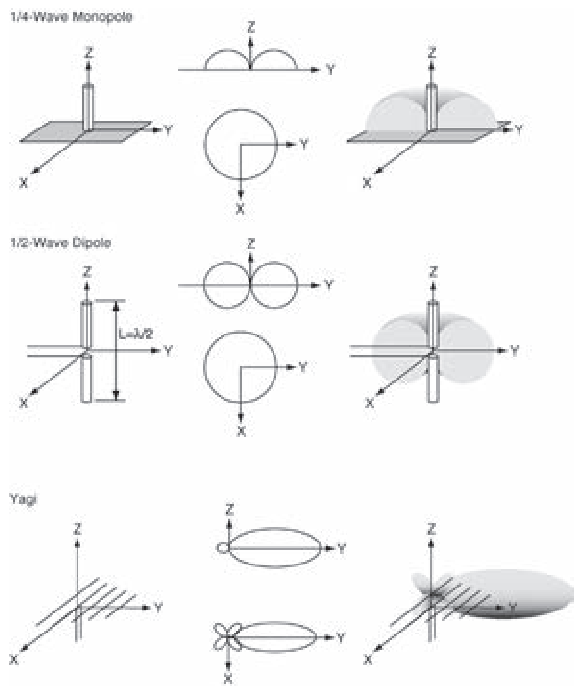


Figure 5: An example of Radiation Patterns.

Antenna radiation patterns can take on many interesting shapes, particularly when presented graphically in their real-world three-dimensional state. The adjoining diagram shows shapes typical of the most popular antenna types. For a dipole antenna, the pattern looks like a doughnut. For a monopole antenna on a ground plane, cut that doughnut in half along the edge and set it on the plane with the antenna sticking up through the middle. The Yagi's directivity can be clearly seen, although that term and the value of these types of plots will become even more apparent as *directivity*, *efficiency* and *gain* are discussed.

After the radiated energy surrounding an antenna is measured, the data is often turned into a radiation pattern plot. This plot graphically presents the way in which the radio frequency energy is distributed or directed by the antenna into free space. An antenna radiation pattern plot is an important tool, since it allows rapid visual assessment and comparison of antennas. The antenna's radiated performance, and thus the corresponding plot, will be influenced by the test jig or product on which the antenna is mounted. This makes the comparison of plots coming from different manufacturers difficult. In addition, the plot for a specific design will likely vary from that of a reference design. Pattern plots typically consist of a polar coordinate graph, though Cartesian coordinate graphs are also used. Polar plots are easier to visualize, as they show the radiated power 360 degrees around the antenna under test. Generally, a logarithmic scale is used, which allows a range of data to be conveniently shown on the same plot. Two plots are created, one in the horizontal axis and one in the vertical axis. Together, these give a picture of the three dimensional shape of the radiation pattern, as demonstrated by Figure 6.

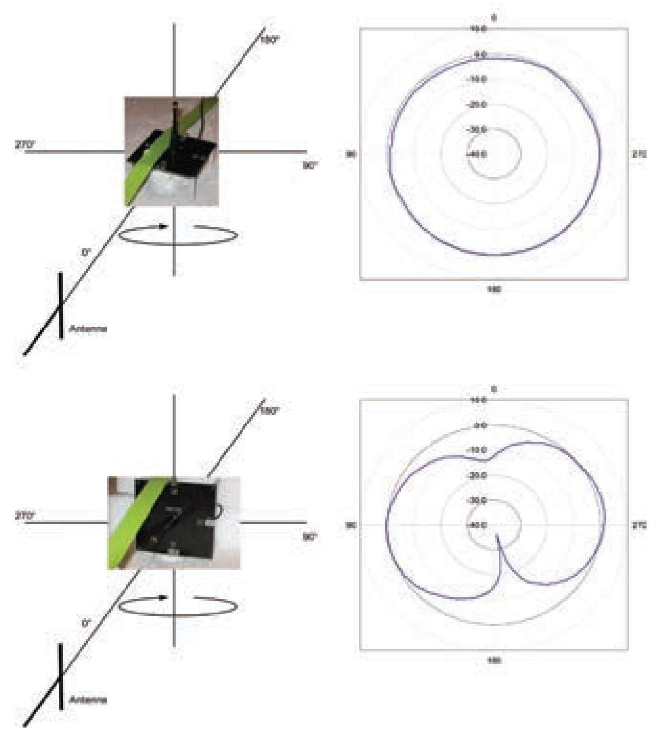


Figure 6: Polar Plots of an Antenna Radiation Pattern.

An antenna's radiation pattern and specifications related to it often need a point of comparison or reference. Most frequently, a theoretical antenna called an isotropic antenna or isotropic radiator is used for this purpose. The term "iso" means the same, "tropic" means direction. Thus isotropic describes an antenna which radiates electromagnetic energy the same in all directions. The isotropic antenna and its perfect spherical pattern are only theoretical and do not actually exist, but the model serves as a

useful conceptual standard against which “real world” antennas and their specifications can be compared. Now it is time to take a closer look at some of the most important radiated specifications and what they mean.

Figure 7: Isotropic Radiation Pattern.

There are three radiated specifications that are of primary interest: efficiency, directivity and gain.

Often these terms are talked about in the context of an antenna’s transmitted signal. It is somewhat easier to visualize these concepts by thinking of radiated power, but it should be recognized they apply directly to reception as well.

Efficiency is a measurement of how much energy put into the antenna actually gets radiated into free space rather than lost as heat on the antenna’s structure or reflected back into the source. The antenna’s impedance and VSWR at the center frequency play a big role in this measurement.

Directivity measures how much greater an antenna’s peak radiated power density is in a particular direction than for a reference radiator with the same source power. It is the ratio of the power density in the pattern maximum to the average power density at a uniform distance from the antenna. In short, it is a comparison of the shape of the radiation pattern of the antenna under test to a reference radiation pattern. Most commonly, the reference would be the perfect spherical pattern of the isotropic model described earlier. The units of this measurement are decibels relative to isotropic, or dBi. A dipole antenna is also sometimes used as a reference, in which case the units be stated in dBd (meaning decibels relative to dipole). A dipole has a gain of 2.15 dB over isotropic or dBi = dBd + 2.15 dB. When comparing gains, it is important to note whether the gain is being expressed in dBd or dBi and convert appropriately.

Gain can be a confusing specification. Most engineers are familiar with the term in reference to amplifiers, where gain is a measure of how much an amplifier increases the input signal. But there is a significant difference between an amplifier’s gain and an antenna’s gain. The amplifier puts energy into the system, making it an active device. An antenna cannot put energy into the system, so it is a passive device. Gain is commonly misinterpreted as an increase in output power above unity. Of course, this is impossible, since the radiated power would be greater than the original power introduced to the antenna.

Directivity and gain are closely related. Gain is the directivity of the antenna reduced by the losses on the antenna, such as dielectric, resistance, and VSWR. In other words, it is the product of directivity and efficiency. Gain is the most direct measurement of an antenna’s real performance. As such, it is one of the most important specifications.

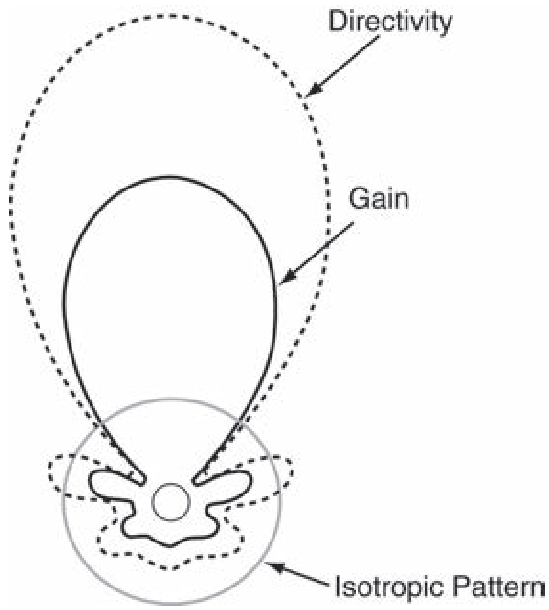


Figure 8: Directivity and Gain.

A simple way to understand directivity or gain is to think of a focusable light source. Assume the light output is constant and focused over a wide area. If the light is refocused to a spot, it appears brighter because all of the light energy is concentrated into a small area. Even though the overall light output has remained constant, the concentrated source will produce an increase in lux at the focus point compared to the wide source. In the same way, an antenna that focuses RF energy into a narrow beam can be said to have higher directivity (at the point of focus) than an antenna that radiates equally in all directions. In other words, the higher an antenna’s directivity and the narrower the antenna’s pattern, the better its point performance will be.

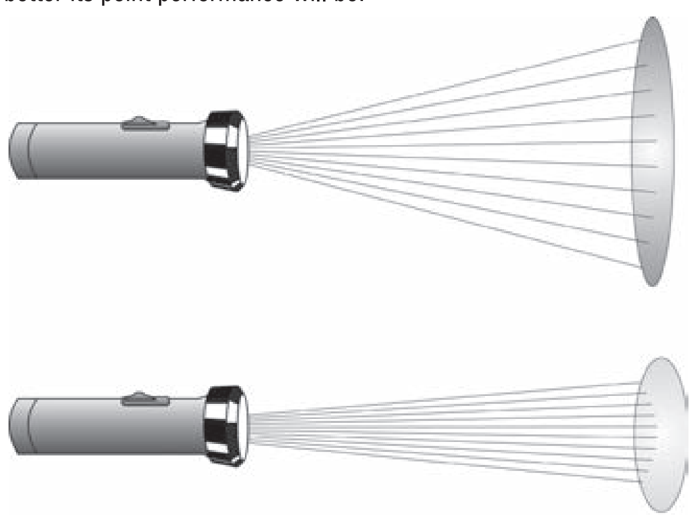


Figure 9: Light Gain

Monopole antenna performance

The performance of a monopole antenna is critically dependent upon the counterpoise used as the other half of the antenna. This counterpoise can be a solid copper fill on a circuit board or a metal enclosure. Since the RF stage is referenced to the circuit ground, this plane or the enclosure are also connected to ground. The size of the ground plane counterpoise as well as its location with reference to the antenna will have a significant impact upon its VSWR and gain.

Typically, antennas are designed on a counterpoise that is one wavelength in radius. At one wavelength, the counterpoise will act sufficiently like an infinite plane. This makes for great specifications, but in the real world a cordless phone will not have a one foot radius ground plane for its antenna. This begs the question, “what happens when the ground plane is reduced to something that is more practical for a portable product?” The answer is, “quite a bit.”

Generally, if the radius of the counterpoise is longer than one wavelength, the performance is close to that of an infinite counterpoise. If the radius is shorter than one wavelength, the radiation pattern and input impedance are compromised. Significant performance reductions occur when the radius is a quarter-wave or less.

In Figure 10, the graphs show the performance of a 916 MHz antenna that has been tuned to a 4” x 4” ground plane counterpoise. Graph A shows the antenna measured on the 4” x 4” ground plane. Graph B shows the antenna measured on a 26.5” x 26.5” full-wave ground plane. Looking at the VSWR graphs, it can be seen that a larger ground plane will lower the resonant frequency and widen the bandwidth. In this case, the wider bandwidth offsets the drop in frequency so that the VSWR at the intended center frequency is still less than 2.0:1.

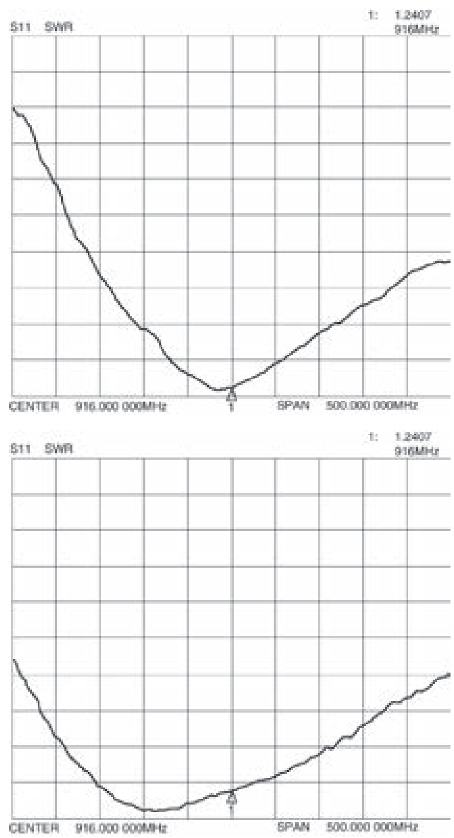


Figure 10: A 916 MHz antenna VSWR on (A) a 4” x 4” ground plane and (B) a 26.5” x 26.5” ground plane.

Conversely, if the antenna had been tuned to the larger plane then placed on the smaller one, the center frequency would have shifted higher and the bandwidth would be smaller. This could result in a VSWR that is out of specification. This effect would be magnified with helical antennas as shown in Figure 3. Helical antennas are coiled to reduce their size, but that also has the effect of narrowing the bandwidth. A ground plane that is too small could narrow the bandwidth to a point where it would be difficult to maintain the antenna’s performance over production tolerances and in the presence of external influences.

Regardless of the antenna style chosen, the size of the implemented ground plane should be considered in comparison to the antenna manufacturer’s reference plane and calculated ideals. Whenever possible, actual antenna performance should be measured with tools such as a network analyzer and spectrum analyzer, since shifts such as those described above can affect the efficiency of the system and significantly impact the product’s final range. If the antenna is mismatched, the transmitter output power could be increased to compensate, but at the cost of higher current consumption and shorter battery life. For most receivers, there is little that can be done to recover the lost sensitivity. In some cases, a Low Noise Amplifier (LNA) can be placed after the antenna and before the receiver’s front end, but that adds to the cost, current consumption and size.

Not only does the size of the ground plane dictate performance, but also the location of the antenna upon that ground plane. The plots in Figures 11a and 11b show the radiation pattern for two 418 MHz antennas on a 4” x 4” ground plane. Both have the same elements, but one is mounted in the middle of the plane and one is mounted on the edge with a right-angle connector. As can be seen from the plots, with the antenna mounted in the middle, the pattern is uniform. With the antenna mounted on the edge of the plane, more energy is radiated away from the plane. This will result in the system having a better range in one direction than in another. This may impact the performance and perceived quality of the final product, so it should be considered early in the design phase.

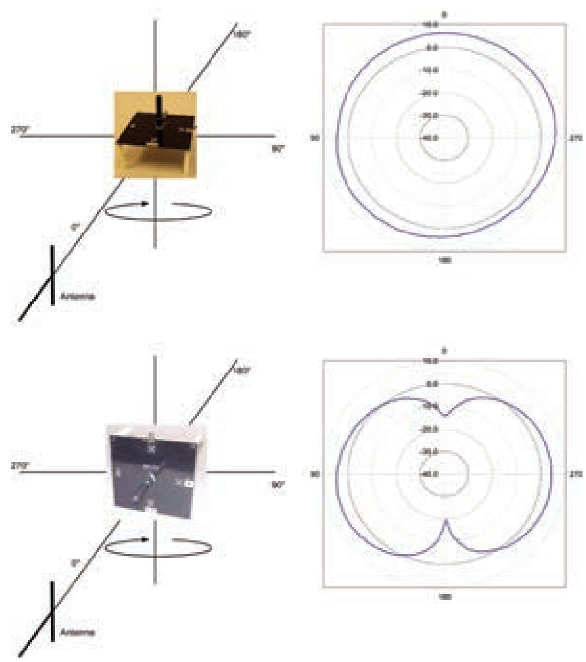


Figure 11a: A 418 MHz antenna radiation pattern on a 4” x 4” ground plane centered.

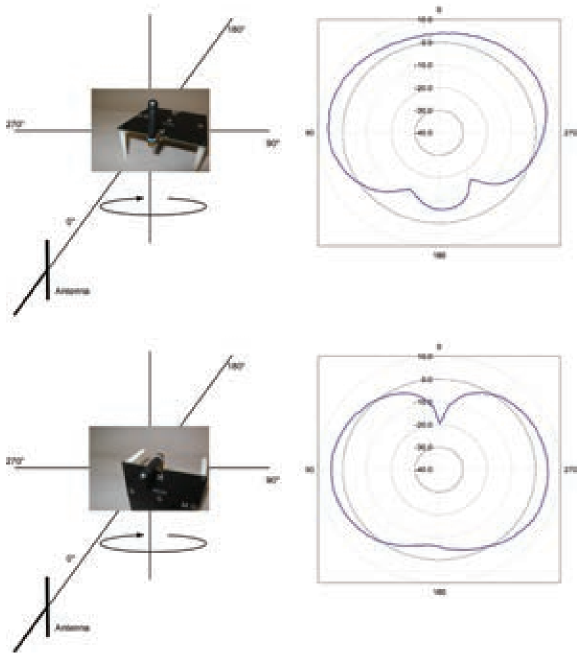


Figure 11b: A 418 MHz antenna radiation pattern on a 4" x 4" ground plane edge mounted.

All of these examples have shown a quarter-wave monopole that is orthogonal to the ground plane. It is also very common to have the antenna in the same plane as the ground. Once again, the ground plane becomes the other element of the antenna system. Figure 12 shows a 916 MHz antenna oriented in this manner.

This orientation is very common in handheld products such as cellular phones. The length of the ground plane that points in the opposite direction from the antenna is critical. Ideally, it would be a quarter-wavelength long, but it can be shorter if the sacrifice in performance can be accepted.

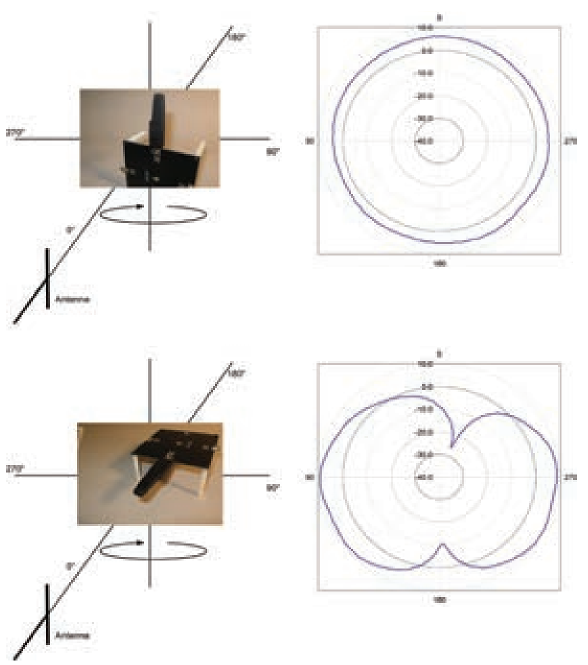


Figure 12: A 916 MHz antenna radiation pattern in the plane of a 4" x 4" ground plane.

These measurements are good for illustrating concepts, but they are only valid for that specific antenna when measured on that specific board. Since anything placed on the board is in the near field (within one wavelength) of the antenna, it will have an impact on the radiation pattern. Any change in the shape of the board within one wavelength will also have an impact on the pattern.

While manufacturers' patterns can give a general idea of the antenna's performance, they often bear no resemblance to the antenna's performance on the final product. Polar plots (for these types of antennas) are expensive to make and do not provide much useful information to the customer. This may be why some antenna manufacturers do not list gain specifications or polar plots for monopole antennas.

However, there are many antenna styles for which manufacturers' gain and radiation patterns are valid. Yagi, parabolic, corner and horn antennas are all types that do not depend on a ground plane provided by the designer. Broadcast antennas for AM/FM radio will often use the Earth as a ground plane (the transmitting towers at the radio station, not the receivers). Since the Earth is much larger than one wavelength at these frequencies, it acts like an infinite ground plane. However, none of these styles would be considered for use in a portable product.

A dipole antenna can also be affected in a similar way by the ground plane, depending on its construction. Some dipole antennas are in the same form factor as whip antennas, but will have a counterpoise as well as the element inside the sleeve. Typically, the counterpoise will be a metal tube with the antenna element positioned on top. A coax cable is attached to the connector and then runs up inside the tube to connect to the tube and element, making a center-fed dipole antenna. In Figure 13, the antenna element is a helical to reduce the overall housing length.

Figure 13: A whip style center-fed dipole antenna.

A common misconception about antennas with an internal counterpoise is that their characteristics are unaffected by external factors. While it is true that an external ground plane is not required for the antenna to operate correctly, if you connect one of these antennas to a product that has a ground plane, you will see the same shifts as shown in Figure 10. The product's external plane will add to the antenna's internal counterpoise and shift the frequency, gain, and radiation pattern. The performance shift can be minimal, but it should be recognized that while a dipole does not require a ground plane, it is not immune to external factors. Part of the attractiveness of a dipole is that an external ground plane is not required for the antenna to perform well. The downside is that dipole antennas are usually larger and more expensive since they have to include the counterpoise internally.

Designing with a quarter-wave monopole antenna

A common pitfall for designers new to the wireless arena is the implementation of the ground plane. As stated earlier, the ground plane is the other half of the antenna, so it is critical to the final performance of the product. This means that it is critical to get it right.

The ground plane is a solid copper fill on one layer of the circuit board that is connected to the negative terminal of the battery. This fill not only acts as the antenna's counterpoise, but is also the ground connection for all of the components on the board. The problems arise when components are added and the traces routed to connect them.

It is a very rare and simple design that does not need to route a trace on more than one layer. Every trace that gets routed on the same layer as the ground plane can have a significant impact on the RF performance. It is best to look at the board from the perspective of the antenna connection. The goal is to have a low impedance path back to the battery or power connection. This is accomplished with wide, unobstructed paths. If the ground plane is cut up with traces, through-hole components, or vias, then it will not be able to do its job as an antenna counterpoise. One of the worst things that can happen is for the ground plane to get so cut up that it has to get connected by jumping back and forth between layers through vias. A via is associated with inductance, which increases its impedance at high frequency. This will result in the ground plane floating somewhere above ground at RF frequencies, which will reduce the performance of the antenna and, consequently, the range of the product.

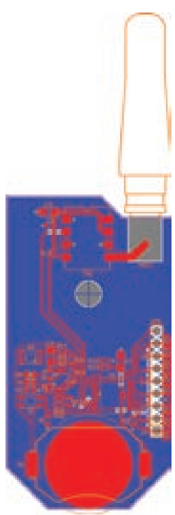


Figure 14: PCB Layout.

When running traces on the ground plane layer, try to present the smallest profile to the antenna, which is normally the width of the trace. This means running traces away from the antenna rather than across the board. Figure 14 provides an example.

This board uses a quarter-wave monopole antenna that is mounted in the same orientation as the ground plane. The top layer is in red and the bottom layer is in blue. Almost all of the bottom layer traces are running away from the antenna (up and down) rather than across its resonant path (left and right). The one through-hole component, SM1, is also running away from the antenna. Looking at the board from the perspective of the antenna, there are very wide paths from the antenna to the battery, B1. This will mean a good, low-impedance ground connection for all of the RF stage, which will maximize the RF performance.

The ground plane also allows for the implementation of a microstrip line between the RF stage and the antenna. This term refers to a PCB trace running over a ground plane that is designed to serve as a transmission line between the module and the antenna. A transmission line is a medium whereby RF energy is transferred from one place to another with minimal loss. This is a critical factor because the trace leading to the antenna can effectively contribute to the length of the antenna, changing its resonant frequency. The width of the microstrip line is based on the desired characteristic impedance of the line, the thickness of the PCB and the dielectric constant of the board material. When implemented correctly, the microstrip line will connect the antenna to the RF stage without affecting the antenna's resonant frequency or the match to the RF stage.

One other thing that frequently seems to catch designers off guard is that standard connectors, such as SMA, BNC and MCX, are illegal for use as an antenna connection in the United States for devices falling under some sections of CFR Part 15. The FCC does not want the end user to be able to change the antenna from the one that was certified with the product. For this reason, the antenna will need to use a non-standard, proprietary, or permanent connection. Fortunately, the FCC considers reverse-polarity connectors to be non-standard, so they are commonly used by OEMs for the antenna.

Putting it all together

The antenna is a critical component to a system's performance and should be considered early in the design process. It should be recognized that specifications on an antenna's data sheet will not necessarily reflect its performance in the final product. This is a result of design-specific factors, such as those discussed here, as well as differing references, methods of test, and presentation formats among antenna suppliers. With this in mind, allowance must be made for testing and optimizing the antenna as an integral part of the overall design process. While it is unlikely an end user will spend much time contemplating the nuances of antenna implementation, they will certainly appreciate the range and reliability of a well-designed product. The field of antenna design and application is complex, but by understanding a few ground rules, it is not necessary to be an antenna designer to design *with* an antenna.

Did You Know?

An antenna's HPBW (half power beamwidth) is defined as the angle of separation between the two half-power points on either side of the main lobe of its radiation pattern.

The specification can often give the user an idea of how directive the antenna is with a smaller beamwidth inferring a more directive antenna. This is most useful with antennas that have a primary direction of propagation, such as Yagi-Uda or horn types.

Antenna Design for Portable Tracking Devices

by Simon Kingsley, *Antenova*

The designer of portable tracking devices is trapped in a space with three types of boundaries: physics, cost, and available technology. All are challenging, but none are insurmountable.

Devices that you can interrogate by cellular radio to find out where the host platforms are located have been around for some time in the form of vehicle trackers and covert devices. Now consumer devices are becoming available that can be used for tracking children, workers, old people, pets, luggage, and other personal property.

The list is seemingly endless. Some trackers are equipped to provide an alert if the device is tampered with, if the host device is removed or even if it goes out of a programmed area (geo-fencing). Trackers can also be equipped with a panic or call button if the device is being worn by a lone worker. Figure 1 shows a credit card size tracking device suitable for lone worker and executive security applications.

Figure 1: Credit card size tracker device with GPS RF Antenna module visible/highlighted at the bottom of the picture. (NB: The GSM antenna cannot be seen in this view.) Device size: 80 mm x 50 mm x 6.9 mm (L x W x H).

In principle, a tracker is a simple device having a GPS receiver so that it knows where it is, and a cellular radio terminal so that it can transmit this information when commanded to do so. However, in practice there are some challenging problems involved in designing the necessary radio system. In this article we look at these problems and see how they can be overcome.

Portable tracking devices come in all shapes – watches, credit card format, USB sticks, dog collars, etc., but unfortunately they mainly come in one size - small. Small form factors create problems with shrinking the GPS and cellular radio components to the limited space available, preventing them from interfering with each other and getting the antennas to transmit or receive signals efficiently.

GPS signals are circularly polarized and, in the past, ceramic patch antennas have mainly been used to receive them. Patch antennas work well in devices with a fixed horizontal orientation because they have a relatively narrow beam looking upwards at the sky. They are efficient if they are large enough and are mounted on a suitably large ground plane. However, in a mobile device such as a tracker, the orientation may vary – so patch antennas are much less suitable.

There is a need for an antenna with a more omni-directional pattern so the orientation of the tracker is less important. Unfortunately, the more omni-directional an antenna pattern is, the lower the antenna gain and, as a result, the satellite signals are received with a slightly weaker signal strength, resulting in lower location accuracy. This, however, is a necessary requirement and is somewhat compensated by the fact that the tracker can receive signals from a greater number of satellites; this in turn can help to recover the location accuracy. Antenova has been working on a number of antennas and radio antenna modules that are specially adapted for very small tracking devices and other mobile GPS units (Figure 2).

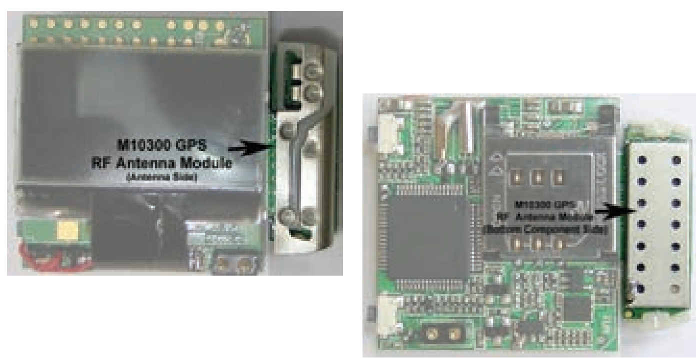


Figure 2: Top and bottom view of a GPS wrist watch design with GPS RF Antenna Module visible/highlighted on the right side of picture. Device size: 45 mm x 38 mm x 17 mm (L x W x H).

The GPS system

The GPS system is based on a constellation of satellites, currently numbering around 30. Each satellite transmits continuous radio signals containing navigation messages, and a GPS receiver calculates its position by careful timing of these signals. One of the most important parameters is the Carrier/Noise ratio (C/N_0), which the receiver computes and reports for each satellite. The Carrier is the wanted signal from the satellite and the Noise is the unwanted background signals. Background thermal noise is always present, but there may be noise from the tracker itself and any other electrical devices that are nearby. With a good C/N_0 (low noise, a good view of the sky and plenty of satellites visible) a stationary GPS tracker can locate itself with a median error of about 2.5 m. When the noise level rises this rapidly gets worse, so it is important to maximize C/N_0.

Navigation systems for cars or hand-held devices used for hiking are relatively large structures and do not generally include a cellular radio. In a small tracking device the GPS receiver and the cellular radio are squeezed into a very small space giving the following problems:

- Noise from the GSM system, the host processor, and even the LCD display (where fitted) may interfere with the reception of GPS signals.
- Coupling between the GSM antenna and the GPS antenna reduces the efficiency of both radio systems.
- GSM transmissions may swamp the GPS front-end LNA creating harmonics and other problems.
- Wideband noise from the GSM PA may desensitize the GPS receiver.
- The close proximity of other components, such as batteries, may affect the performance of both radio systems.
- The space available for the GPS antenna may not be suitable for the best signal reception. With tracking devices, the orientation of the device in use is unknown and so an antenna pattern that is as omni-directional as possible is required. There will always be one location for the antenna that is best for omni-directional coverage, but this position may not be available because of the ID of the device and the layout of all the other components. This is less of a problem on larger platforms.

The solution to these issues lies in careful system design and a good understanding of antennas. Coupling between the GSM, GPS radios and antennas, for example, may be minimized by mounting them on opposite sides of a PCB. A blocking filter before the GPS LNA, and a second one after it, can prevent the GSM transmissions affecting the GPS system. Figure 1 shows a module on which we have identified the main GPS and GSM components. Combining the radio and antenna is particularly useful for the GPS system where the radio and antenna are roughly the same size and can be manufactured as a single radio antenna unit; optimizing the design is then a matter of good design practice and know-how. It is also important to have good measurement facilities for both passive and active testing. Testing is usually carried out in an anechoic chamber equipped to emulate the signals coming from GPS satellites and from cellular base stations.

The GSM system

Although the 3G network may be used for trackers, GSM is usually preferred because of its more universal coverage. The DCS and PCS bands are not usually a significant problem for the tracker designer, but the two low frequency bands at 850 and 900 MHz are a major problem. If you ask the question: "can an antenna be made indefinitely smaller?" the answer is "no," there is a physical limit. This limit, sometimes called the Chu-Harrington limit, is related to the smallest volume that will enclose the antenna, expressed in wavelengths. If a small antenna working at long wavelengths falls below this limit, then either bandwidth or efficiency will be lost. The ideal length of a mobile phone for low-band GSM performance is around 120 mm, but reasonable performance can be achieved down to about 80 mm. Unfortunately, many tracking devices are as little as 40 mm in their largest dimension so the antenna design is a significant challenge.

Every antenna must have two halves – the antenna itself is one part and the PCB usually forms the other. The only exception to this is when the antenna itself has two halves, such as with a dipole antenna. With a typical tracker antenna arrangement, the antenna must be very small as many other components must fit inside the tracker box. In effect the PCB is the main radiating component and its lack of length becomes critical. What can be done about this problem? One solution is to extend the PCB groundplane outside the box as part of any external features, such as the strap on a watch-based tracker or the collar on a pet tracker. Even a loop on the end of the tracker for attaching a cord can make a useful difference to the antenna performance. If no external features are available, it is worth considering using a balanced dipole-like structure, having two antenna arms, because it may be possible to get them a long way apart by attaching them to the inside of the box at opposite ends. This distance can be greater than that between a single antenna and the PCB.

Constraints and tradeoffs

The designer of portable tracking devices is trapped in a space with three types of boundaries. One boundary is the laws of physics that limit how effective a small antenna can be – there is not much that can be done about this except to make use of good engineering practice and experience. Another boundary is cost, because trackers must often be inexpensive devices – engineering for cost reduction is an established and effective art, but it does not increase the designer's options. The third restriction is formed by the technology available. For example, if better components were available, could the tracker design and performance be improved? Let's look at this.

A typical complete GSM module that might be used in a tracker measures roughly 30 x 30 x 5 mm and the battery is often a similar size. These two components take up the majority of space available as the processor and GPS systems are generally smaller. Suppose that the whole of the GSM radio could be shrunk to a single chip or a much smaller module. Suddenly a lot of space is freed up in the tracker, but how best to use it? It would not help to make the box smaller, as we have seen. But perhaps the box could be made longer and thinner, especially if a suitable battery could be chosen. The tracker now becomes a thick strip that might be hidden in the frame of a valuable painting or concealed in the lining of a luxury designer bag, just to give two possible examples.

Now imagine that we introduce flexible printed circuit technology together with a curved battery. Our strip tracker can be turned into the watch strap, instead of being part of the watch, or become part of a dog collar or a belt. The long format of the device would mean the GSM radio would work well and the device would be easier to hide. At present, the size and rigid shape of the SIM card and holder would prevent this type of design being realized, so a new SIM card format would be needed. These considerations show that improved components can help the designer and so this is the boundary to push at.

Lessons learned

Low-cost tracking devices are growing in popularity and will find an ever-increasing role in protecting people and property. It is not easy to design the radios in these devices, but what we have learned so far is:

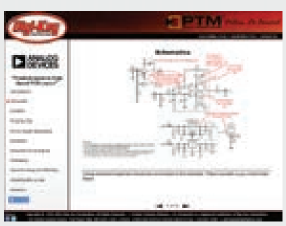
- Both GPS and GSM radios and antennas must be designed in from the start of the tracker development to ensure they are located in the best possible positions for efficient radiation and minimum coupling between them.
- Greater integration is needed between radios and antennas to create compact modules that are easy to build into prototypes.
- Because of the small size of trackers it is necessary to have a good understanding of those laws of physics applying to small antennas, and how they relate to tracker applications.
- It is important to keep abreast of the latest technology and devices available, as well as pressing for ever smaller and more integrated components.

Antenova's GPS RADIONOVA RF antenna module contains both the antenna and all the RF and signal-processing circuits, and requires only the addition of some processor power on the motherboard and appropriate application software. The module provides a complete RF subsystem for the addition of GPS and location functionality to a portable tracking device, and has been demonstrated to be the most versatile and capable solution in terms of both RF and satellite acquisition performance for this application.

Practical Guide to High Speed PCB Layout

Analog Devices, Inc.

Analog Devices' guide to PCB layout comes with a detailed schematic or blueprint of properly designed PCBs and offers advice regarding parasitics, ground and power planes, packaging, and signal routing and shielding.



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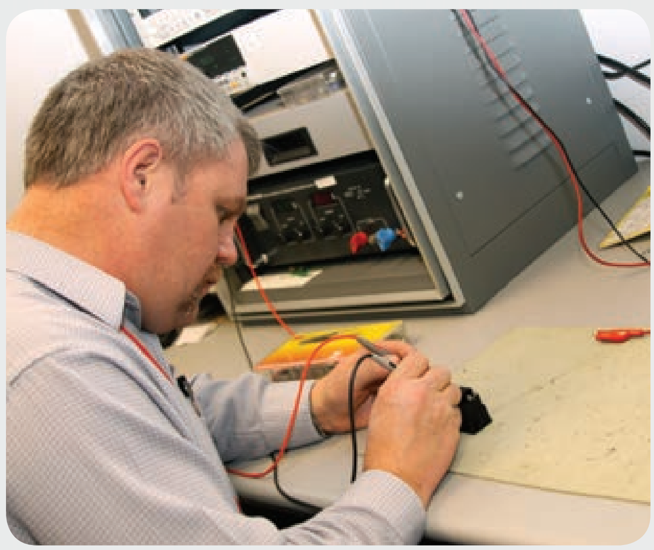

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AVR2021: AT86RF231 Antenna Diversity

contributed by Atmel Corporation

Antenna diversity is your best protection against multipath fading. Using it can considerably improve the reliability of real-world network implementations.

Antenna Diversity is a transmission method using more than one antenna to receive or transmit signals along different propagation paths to compensate for multipath interferences.

Due to multipath propagation interference effects between network nodes, the receive signal strength may strongly vary, even for small changes of the propagation conditions, affecting the link quality. These fading effects can result in an increased error floor or loss of the connection between devices.

Applying Antenna Diversity transmission techniques in such scenarios improves the reliability of an RF connection between network nodes.

This article describes the usage, design, and layout of the AT86RF231 Antenna Diversity, an implementation is shown in Figure 1. The information provided is intended as a helping hand for hardware designers to make use of the AT86RF231 Antenna Diversity capabilities.

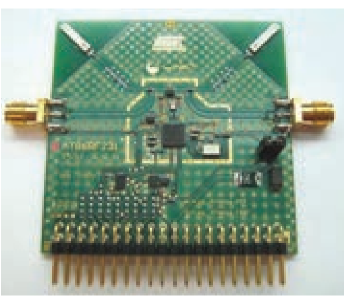


Figure 1: AT86RF231 – Antenna Diversity Radio Extender Board.

Wireless communication channel models

In wireless communication systems different channel models are used to describe the behavior of the air interface. A simple model is additive white Gaussian noise (AWGN). This model assumes a linear addition of wideband noise to the wanted signal with a constant spectral density and a Gaussian distribution of the amplitude.

More realistic wireless channel models also consider the impact of multipath propagation. Since a transmitted signal is subject to reflections and refraction on walls, surfaces etc., the receiving node will see many signals, each differing in phase and amplitude. All signals superpose at the receiving antenna causing an effect called fading.

Using more than one antenna allows the evaluation of different multipath scenarios to avoid or reduce the effects of fading or interferences. Assuming that these antennas are independent of each other with respect to the signal propagation paths, the probability that all of them suffer from fading at the same time is significantly reduced.

AT86RF231 Antenna Diversity

The AT86RF231 Antenna Diversity (AD) feature supports the control of two antennas to select the most reliable RF signal path.

A differential control pin pair, pin 9 (DIG1) and pin 10 (DIG2), is used to control an external RF-switch selecting one of the two antennas. During synchronization header (SHR) search, the radio transceiver autonomously switches between the two antennas, without the need for microcontroller interaction, if the AD algorithm is enabled.

To ensure highly uncorrelated receive signals on each antenna, the antennas should be carefully separated from each other (refer to the section “Multipath Propogation Characteristics”).

If enabled, and when the AT86RF231 is set into a receive state, the automated AD algorithm works as follows: On detection of an SHR with a sufficient high signal level on one antenna, this antenna is locked for reception of PHR and PSDU. In this case, no further attempt is made to determine the signal level on the other antenna. Otherwise the SHR search is continued on the other antenna and vice versa.

After the completed reception of a frame, indicated by an interrupt IRQ_3 (TRX_END), the diversity search algorithm is continued until a new SHR header is detected or the receive state is left.

Application Schematic

Figure 2 illustrates the AT86RF231 Application Schematic concentrating on Antenna Diversity.

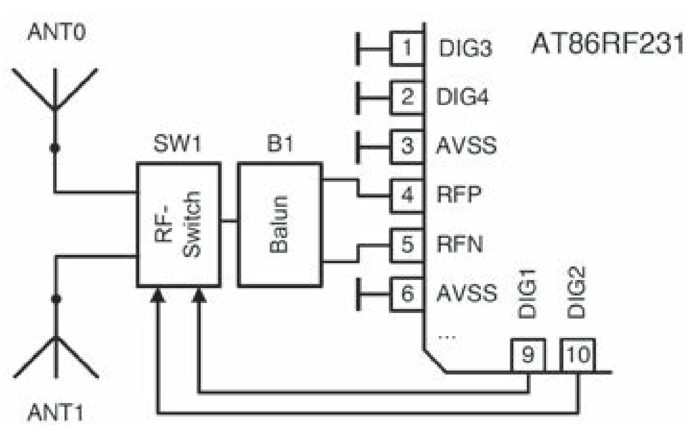


Figure 2: AT86RF231 Antenna Diversity – Application Schematic.

Two antennas, ANT0 and ANT1, are connected via an RF-switch (SW1) to a balun (B1). A differential control pin pair (DIG1/DIG2) selects one of the two signal paths within SW1 to connect one antenna to the radio transceiver during receive or transmit. Balun (B1) transforms the single-ended port impedance of 50 Ω to the 100 Ω differential RF port impedance at pins RFP/RFN. [1]

Configuration

It is recommended to configure Antenna Diversity in one of the transceiver states TRX_OFF, PLL_ON or TX_ARET_ON. [1]

Generally, the automated Antenna Diversity is enabled with register bit ANT_DIV_EN (register 0x0D, ANT_DIV) set. In addition, the control of the Antenna Diversity RF-switch (SW1) must be enabled by register bit ANT_EXT_SW_EN (register 0x0D, ANT_DIV). In this case the internal pull-down of the control pins DIG1/DIG2 is disabled, and they feed the antenna switch signal and its inverse to the differential control inputs of SW1. The voltage level of DIG1/DIG2 is equal to DEVDD.

To actually receive a frame, applying the AD algorithm, the AT86RF231 state must be changed to RX_ON or RX_AACK_ON.

Receive diversity procedure

Exemplary, the function and behavior of the control signals DIG1/DIG2 during receive is shown in Figure 3.

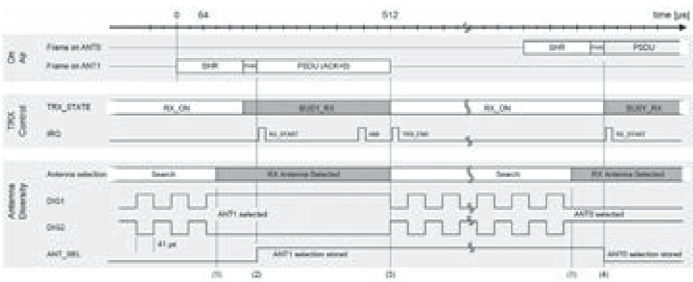


Figure 3: Antenna Diversity Operating Principle during Receive.

Assuming a frame with a sufficient signal level is available at antenna ANT1 only, the AD algorithm selects this antenna while searching for the SHR (1). During the rest of the frame reception this configuration is fixed. The selected antenna can be determined by reading register bit ANT_SEL at the time when interrupt IRQ_2 (RX_START) is issued (2).

Immediately after the successful frame reception, indicated by an interrupt IRQ_3 (TRX_END), the AD algorithm starts searching again (3). This continues as long as the radio transceiver is in RX_ON or RX_AACK_ON state. Leaving one of the receive states stops the AD algorithm.

The register bit ANT_SEL maintains its previous value (from the last received frame) until a new frame has been detected, indicated by IRQ_2 (RX_START), see (4). That is at the earliest:

$$t_{TR,ANT\_SEL} = t_{TR27} + 2 * t_{sym} \quad for\ t_{TR27} = 96\ \mu s, t_{sym} = 16\ \mu s$$

If the AT86RF231 is not in a receive state or a transmit state, it is recommended to disable register bit ANT_EXT_SW_EN to reduce the power consumption or avoid leakage current of an external RF-switch, especially during SLEEP state. If register bit ANT_EXT_SW_EN = 0, output pins DIG1/DIG2 are pulled-down.

Transmit diversity procedure

With the AT86RF231 Antenna Diversity feature, upon reception of a frame, the selected antenna is indicated by register bit ANT_SEL. This register bit maintains its value until a following frame has been detected (refer to the previous section).

In contrast to that, the antenna defined by register bits ANT_CTRL (register 0x0D, ANT_DIV) is used for transmission. If, for example, the same antenna should be used for transmission as being selected by the AT86RF231 for reception, the antenna must be set using register bits ANT_CTRL (register 0x0D, ANT_DIV), according to the value read from register bit ANT_SEL. At the earliest, IRQ_2 (RX_START), as an indication of successful PHR reception, can be used to set register bits ANT_CTRL, refer to Figure 4 (1). However, for RX_AACK it is recommended to enable IRQ_3 (TRX_END) only. [1] This interrupt is issued if a frame passes the frame filtering and has a valid FCS.

When reading register bit ANT_SEL, e.g. after IRQ_3 (2), the timing requirements of the succeeding operation have to be taken into account:

1. Transmitting an acknowledgement frame requires setting of the transmit antenna after occurrence of IRQ_3 within a TurnaroundTime: [3]

$$t_{TR,ANT\_CTRL} = 12 * t_{sym}$$

2. Transmitting an acknowledgement frame in slotted operation mode requires setting of the transmit antenna after occurrence of IRQ_3:

$$t_{TR,ANT\_CTRL} = 6 * t_{sym}$$

As an example, the application of Antenna Diversity in Extended Operating Mode RX_AACK is shown in Figure 4. In contrast to the example in Figure 3, an acknowledgement frame is automatically transmitted after a TurnaroundTime (3). To define, that the same antenna is used for transmission as for reception, the register bits ANT_CTRL are to be set within t_{TR,ANT_CTRL}, accordingly.

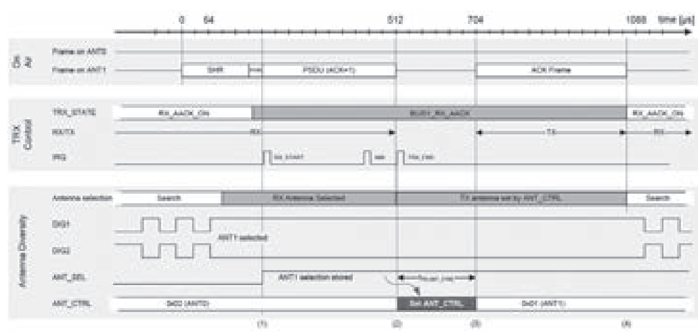


Figure 4: Antenna Diversity in Extended Operating Mode.

In general, the AD algorithm and timings are identical for Basic and Extended Operating Modes. [1]

Dynamic and static antenna selection

Even without using the automated AD algorithm, one antenna can be selected permanently. This may be useful if the Antenna Diversity selection is performed using another control entity than the PHY.

To select one antenna permanently, the antenna has to be configured using register bits ANT_CTRL. This setting defines the antenna for a transmission as well as for reception. The AD algorithm shall be disabled (register bit ANT_DIV_EN = 0) and the control of RF-switch shall be enabled (register bit ANT_EXT_SW_EN = 1).

Antenna diversity sensitivity control
Due to a different receive algorithm used by the AD algorithm, the sensitivity of the receiver has to be adjusted. To achieve this it is recommended to set register bits PDT_THRES (register 0x0A, RX_CTRL) to 0x3.

If the AD algorithm control is disabled, and one antenna is permanently selected using register bits ANT_CTRL, the register bits PDT_THRES shall be reset.

Register Description
Register 0x0A (RX_CTRL):

The RX_CTRL controls the sensitivity of the Antenna Diversity Mode.

Bit	7	6	5	4	
0x0A	Reserved	Reserved	Reserved	Reserved	RX_CTRL
Read/Write	R/W	R/W	R/W	R/W	
Reset Value	1	0	1	1	

Bit	3	2	1	0	
0x0A	PDT_THRES	PDT_THRES	PDT_THRES	PDT_THRES	RX_CTRL
Read/Write	R/W	R/W	R/W	R/W	
Reset Value	0	1	1	1	

- Bit 7:4 – Reserved
- Bit 3:0 – PDT_THRES

These register bits control the sensitivity of the receiver correlation unit. If the AD algorithm is enabled, the value shall be set to PDT_THRES = 3, otherwise it shall be set back to the reset value.

Table 1: Receiver Sensitivity Control

Register Bit	Value	Description
PDT_THRES	0x7	Reset value, to be used if AD algorithm is disabled
	0x3	Recommended correlator threshold if AD algorithm is enabled
	Other	Reserved

Register 0x0D (ANT_DIV):

The ANT_DIV register configures and controls Antenna Diversity.

- Bit 7 – ANT_SEL

This register bit signals the currently selected antenna path. The selection is based either on the last antenna diversity cycle, if automated Antenna Diversity is enabled (ANT_DIV_EN = 1), or on the content of register bits ANT_CTRL (refer to the previous section "Transmit Diversity Procedure").

Table 2: Antenna Diversity - Antenna Selection

Register Bit	Value	Description
ANT_SEL	0	Antenna 0
	1	Antenna 1

- Bit 6:4 – Reserved
- Bit 3 – ANT_DIV_EN

This register bit controls the AD algorithm. On reception of a frame the algorithm selects an antenna autonomously during SHR search. This selection is kept until:

- A new SHR search starts
- The receive state is left
- Disabling AD algorithm
  - Selected antenna is defined by register bits ANT_CTRL
- Bit 2 – ANT_EXT_SW_EN

Table 3: Antenna Diversity Algorithm Control

Register Bit	Value	Description
ANT_DIV_EN	0	Automated AD algorithm disabled
	1	Automated AD algorithm enabled

Note: If ANT_DIV_EN = 1 register bit ANT_EXT_SW_EN shall be set to 1, too.

If enabled, pin 9 (DIG1) and pin 10 (DIG2) become output pins and provide a differential control signal for an Antenna Diversity switch. The selection of a specific antenna is done either by the AD algorithm (ANT_DIV_EN = 1), or according to register bits ANT_CTRL if the AD algorithm is disabled.

Do not enable Antenna Diversity RF-switch control (ANT_EXT_SW_EN = 1) and RX Frame Time Stamping (IRQ_2_EXT_EN = 1) at the same time. [1]

As long as register bit ANT_EXT_SW_EN is set, the control pins DIG1/DIG2 are activated in all radio transceiver states. If the AT86RF231 is not in a receive or transmit state, it is recommended to disable register bit ANT_EXT_SW_EN to reduce the power consumption or avoid leakage current of an external RF-switch, especially during SLEEP state. If register bit ANT_EXT_SW_EN = 0, output pins DIG1 and DIG2 are pulled-down.

Table 4: Antenna Diversity RF-Switch Control

Register Bit	Value	Description
ANT_EXT_SW_EN	0	Antenna Diversity RF-switch control disabled
	1	Antenna Diversity RF-switch control enabled

Notes: 1. If ANT_DIV_EN = 1 register bit ANT_EXT_SW_EN shall be set to 1, too.
2. If ANT_EXT_SW_EN = 1 register bit IRQ_2_EXT_EN shall be set to 0.

- Bit 1:0 – ANT_CTRL

These register bits provide a direct, static control of an Antenna Diversity switch. Setting ANT_DIV_EN = 0 (Antenna Diversity disabled), this register setting defines the transmit or receive antenna.

Table 5: Antenna Diversity - Static Antenna Selection

Register Bit	Value	Description
ANT_CTRL	0	Reserved
	1	Antenna 1, DIG1 = H DIG2 = L
	2	Antenna 0, DIG1 = L DIG2 = H
	3	Default value for ANT_EXT_SW_EN = 0. Mandatory setting for applications not using AD.

Note: The register values 1 and 2 are mandatory for ANT_DIV_EN=1 and ANT_EXT_SW_EN = 1.

AT86RF231 Antenna Diversity - Radio Extender Board

Overview

An AT86RF231 Radio Extender Board supporting Antenna Diversity (AD-REB) is shown in Figure 1. The interface between the radio transceiver and the microcontroller is similar to the basic application schematic. [1]

Schematic

An excerpt of the AD-REB schematic with focus on the RF section is shown in Figure 5.

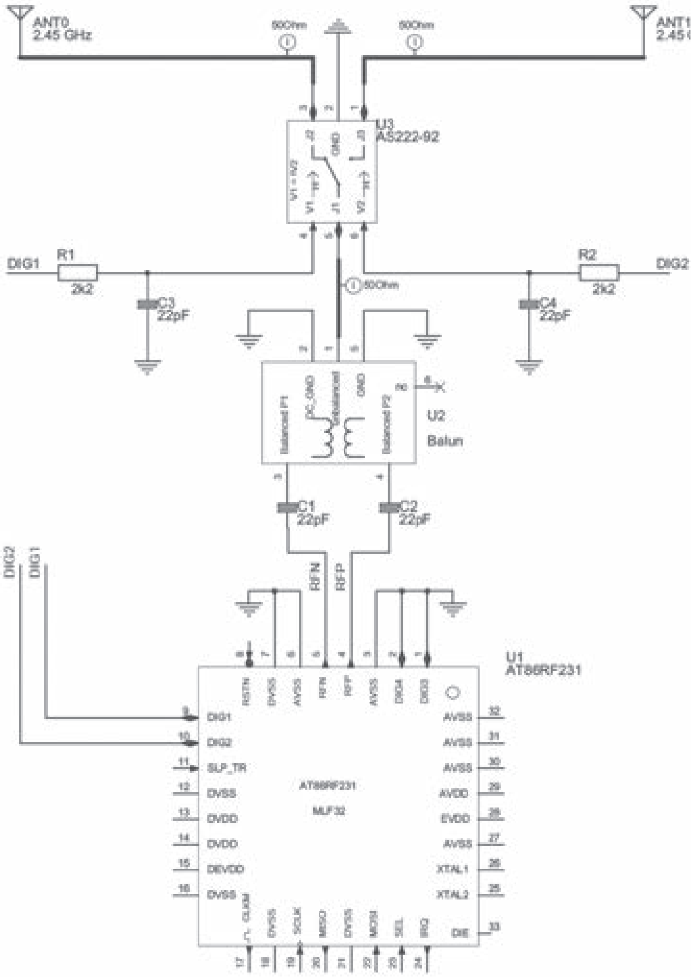


Figure 5: AT86RF231 AD-REB RF Section Schematic

Layout

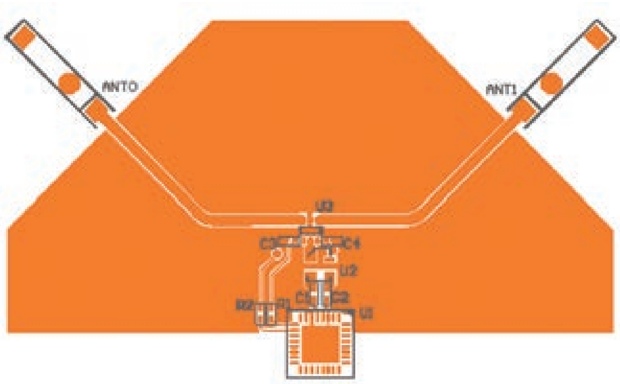


Figure 6: AT86RF231 AD-REB RF Section Layout

Diversity Antenna Considerations and Implementation Details

The AT86RF231 AD-REB implementation makes use of both, space and polarization diversity. Polarization diversity is the ability to receive orthogonally polarized waves with independent propagation characteristics. Therefore the antennas are placed with a specific distance and angle. The distance can be derived, for instance, from the width of the deep fade regions as shown in Figure 9.

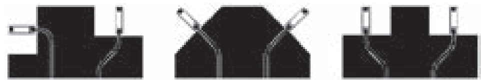


Figure 7: Antenna Configuration Examples

The placement onto the PCB FR4-substrate plane offers various possibilities in the configuration of the two antennas, as shown in Figure 7. The first and the second example using different polarization planes. Here the antennas are placed with an angle of 90 degrees to each other. The advantage of the second configuration is a higher symmetry, which makes antenna matching and board layout easier. The third antenna placement is a symmetric configuration, however, does not support polarization diversity.

Additional Notes:

- The RC components placed between pins DIG9/10 and the RF-switch filter possible transient switching noise of the AT86RF231 control pins, to avoid coupling into the antenna paths. The RC filter consists of R1-C3/R2-C4.
- RF-switch (SW1) is recommended to have low insertion loss (typ. < 1 dB) and high isolation (typ. > 20 dB). No DC path should exist in the antenna paths to make switching with single ended positive voltages possible, refer to the RF-switch datasheet.
- The antenna paths are grounded coplanar lines with a characteristic impedance of 50 ohms.
- The SW1 switching time to select one antenna should be below 1 µs.

Table 6: AT86RF231 AD-REB – RF Section Bill-of-Material (BoM)

Designator	Value	Description
ANT0, ANT1	2.45 GHz	Ceramic antennas
C1, C2, C3, C4	22pF	Ceramic capacitor
R1, R2 U1	2k2 AT86RF231	Resistor 802.15.4 2.4 GHz Radio Transceiver, refer to [1]
U2	WE748421245	SMD-BALUN, Würth
U3	AS222-92	RF-Switch, Skyworks

Measurement Results

Measurement Setup

Measurements are provided to demonstrate the performance improvement of a network node operating in a typical multipath indoor environment when using Antenna Diversity compared to a predefined antenna configuration.

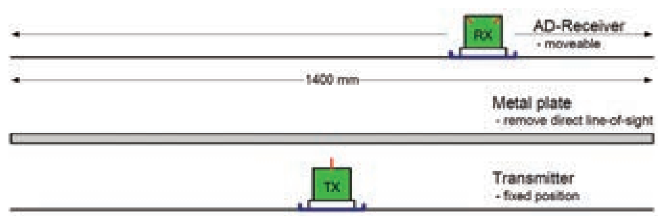


Figure 8: Antenna Diversity Measurement Setup

Node 1 (RX), equipped with two antennas, see Figure 9, is stepwise moved along a fixed track. Node 1 stops at each measurement point. It receives a frame and evaluates its energy detection (ED) level. [1]

Node 2 (TX) is situated in a fixed position, permanently transmitting frames. The transmitter is equipped with only one 2.4 GHz $\lambda/4$ whip antenna and therefore does not use transmit Antenna Diversity.

The measurement setup has no direct line-of-sight between the two nodes. Therefore the propagation scenario is determined by multipath. Additionally, the scenario of the indoor environment must be kept static during the measurement process.

To investigate the multipath propagation characteristics, (see Figure 9) the transmit power is set such that the average receiving power is between -60 to -65 dBm.

During the PER measurements, the transmit power of node 2 is adjusted (see Figure 10) to reduce the average received signal power to a value slightly above the sensitivity limit of -101 dBm. [1] This is necessary to illustrate the effect of deep fades and to create a reasonable average packet error rate.

At each track position the packet error rate (PER) is measured, using 200 packets and a frame length of 50 octets.

Multipath Propagation Characteristics
Exemplary, a measurement result of a 2.4 GHz multipath scenario in a laboratory environment is shown in Figure 9. One curve represents the received signal power at one single antenna. The received signal power is measured at each antenna separately using an ED measurement.

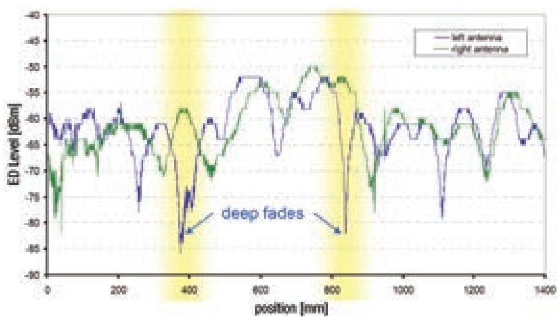


Figure 9: Multipath Propagation Fading Effects

The received signal power at the two antennas varies up to more than 25 dB at certain measurement points, refer to positions 380 mm and 850 mm for instance, or up to 35 dB over the measurement distance. When assuming a larger distance between the two nodes or a more complicate multipath scenario the average received signal power is significant lower. Then one antenna may not receive a sufficient high signal power to correctly receive a frame. In this case the other antenna is selected to receive the frame.

Figure 9 further shows that a distance of about $\lambda/2$ between the two diversity antennas is required to effectively distinguish between different multipath channels. The AT86RF231 Antenna Diversity Radio Extender Board V-shape placement of the two antennas offers in addition linear antenna polarization. This improves the ability to separate between orthogonally polarized multipath channels.

Even if in this example node 1 changes its position, a similar behavior is observed if the environment changes and the two nodes are at a fixed position.

Network Performance Measurements
A measurement illustrating the node-to-node performance using the packet error rate (PER) is shown in Figure 10. The result consists of three individual measurements:

1. Use ANT0 only (left antenna)
2. Use ANT1 only (right antenna)
3. AD algorithm enabled (auto decision)

When using Antenna Diversity there are three possible scenarios for two antennas:

1. Both antennas behave different:
   - One antenna with a good signal quality (PER $\rightarrow$ 0)
   - The other does not receive (PER $\rightarrow$ 1)
2. Both antennas provide a good signal quality (PER $\rightarrow$ 0)
3. Both antennas do not receive (PER $\rightarrow$ 1)

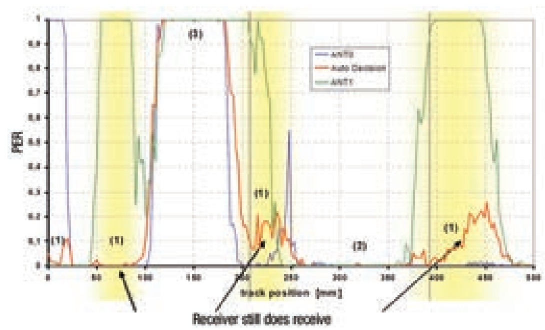


Figure 10: Antenna Diversity Validation Results

The measurement result in Figure 10 shows that for scenarios of type (1), when one antenna is receiving while the other one doesn't, the resulting PER is still at an acceptable low level when using the AD algorithm.

If both antennas provide a sufficient high signal quality (scenario 2) the Antenna Diversity can not improve the link quality further.

Only if both antennas do not receive anything, also Antenna Diversity can't provide better results, scenario type (3).

Conclusion

In environments with distinctive multipath scenarios or varying propagation conditions the application of Antenna Diversity ensures a significant higher probability to access a network node. Thus connectivity between network nodes is improved.

Effects, that nodes are not accessible since they are in a deep fade, are prevented. This may happen even in well established network installation, if for examples the environmental conditions changes.

The use of the AT86RF231 Antenna Diversity transmission technique considerably improves the reliability of real-world network implementations.

This is achieved without increasing the link budget of a network connection, e.g. by using a higher transmit power or and additional pre-amplification (LNA) during receive.

References
[1] AT86RF231; Low Power, 2.4 GHz Transceiver for ZigBee, IEEE 802.15.4, and ISM Applications; Datasheet; Rev. 8111A-AVR-04/08; Atmel Corporation

[2] AT86RF231; Software Programming Model; Rev.1.1; Atmel Corporation

[3] IEEE Std 802.15.4™: Wireless Medium Access Control (MAC) and Physical Layer (PHY) Specifications for Low-Rate Wireless Personal Area Networks (LRWPANs)

M2M COMMUNICATIONS

M2M, or Machine-to-Machine communications, is broadly defined as a physical device that has the capability to communicate with a network. Often this communication piece is most efficient and cost effective when it's implemented via a wireless radio. Choosing the right technology or deciding if a technology meets your application requirements can be a difficult process. This range of articles will provide an overview of available technologies for this purpose and how to overcome some technical roadblocks you may face along the way. Whether you are looking for a control solution or being able to monitor a sensor within a device and beyond, we hope you find this selection of articles valuable.

Optimizing Security Sensor Battery Life

contributed by Ember Corporation

Security sensors are often plagued by short battery life. By combining a low-power wireless protocol with a low-power processor, this doesn't have to be a problem.

Broadband service providers (BSPs), such as cable and telecom companies, are preparing to roll out residential security services—based on the ZigBee wireless specification—to augment their current voice, video, and data services. ZigBee enables BSPs to offer a range of additional services, such as security, energy management, lighting control, and health care applications, which are known collectively as Security, Monitoring, and Automation (SMA) services.

Security sensor battery life represents a key consideration in the practicality, cost effectiveness, and market acceptance of SMA solutions, ranking high on a list of factors that includes wireless communication range, interoperability, certification, ecosystem, and in-field upgradeability. The SMA solution developed by Ember Corporation and iControl, Inc. specifically addresses extending the battery life of contact sensors. This article discusses the results of this engineering partnership.

Ember Corporation is a leader in low-power, wireless networking solutions based on the ZigBee protocol; it has developed industry-leading solutions for a variety of low-power ZigBee devices in addition to security sensors, including gas meters, door locks, and battery-powered thermostats. iControl is the leading provider of SMA solutions that enable BSPs to roll out next-generation services to their customers. In addition to contact sensors, iControl's SMA Platform integrates a wide variety of ZigBee sensors, including motion sensors, smoke alarms, glass break detectors, CO detectors, key fobs, wireless keypads, garage door openers, and more.

Based on the fact that the average residential security system is used for seven years, BSPs typically require that contact sensors have a minimum of three years of battery life for an initial product offering, and a roadmap leading to battery life spans of seven to ten years.

Through collaborative development work, Ember and iControl have optimized the sensor and radio operations most critical to battery life and have projected a battery life well over three years. These results were achieved through iControl's utilization of Ember's industry-leading EM357 ZigBee System-on-Chip (SoC), fine-tuning of iControl's security sensor network operation, and software optimizations in Ember's ZigBee software.

Looking ahead, Ember has identified a host of other software optimizations that will push iControl's contact sensors well into a battery life span of over ten years.

Basics of iControl's ZigBee-based SMA Platform

The award-winning SMA Platform developed by iControl pairs its open, technology agnostic software infrastructure with the industry's only "All-In-One" SMA TouchScreen—combining an alarm system, communications gateway, and home automation platform into one device. The components include an SMA TouchScreen console, a variety of security sensors, and easy integration with third-party devices such as thermostats, lighting controls, and door locks. Ember's ZigBee software provides the two-way wireless networking infrastructure for the entire system as shown in Figure 1.

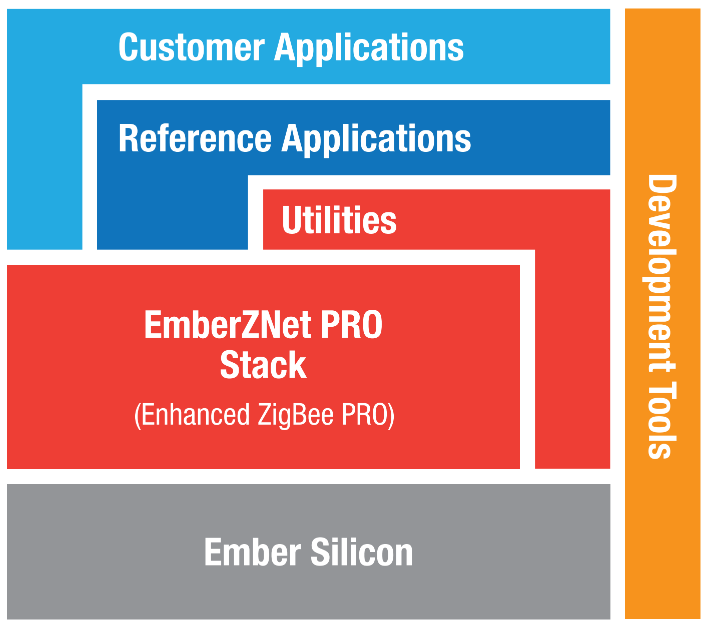


Figure 1: Ember ZigBee networking software.

iControl's security sensors

At the heart of each iControl security sensor is the Ember EM357 processor, which is based on a 32-bit ARM Cortex-M3 processor. The EM357 is the industry's leading ZigBee processor in both current consumption and radio frequency (RF) performance.

Contact sensors are used for door and window security. They are either closed or open; a general-purpose input-output (GPIO) line on the Ember EM357 is used to sense the state of the switch. The double-throw switch draws no current until it senses the door or window opening or closing. During deep sleep, the sensor consumes only 0.65 µA, which comes from the power used by the EM357 to perform the periodic data polls.

The iControl contact sensor components include the following:

- Ember EM357 ZigBee SoC
- Power amplifier and low-noise amplifier circuit
- Reed switch: the simple open-close switch mechanism that monitors the state of doors and windows
- One CR2 battery, rated at 800 mAh

Figure 2 shows the iControl contact sensor.

Figure 2: iControl contact sensor.

Technical background

When calculating battery life, it is necessary to understand the four factors that drive power consumption:

- Operating states
- Sensor and radio parameters
- Various measurement units utilized in the calculations themselves
- Battery technology

Operating states

Every activity that the security sensors perform falls into one of two types of operating states: steady-state operation or periodic events. This section explains each of these operating states and how the average current consumed for each is measured.

Steady-state operation

Steady-state operation is the normal idle state with minimal current drain while the sensor is sleeping. The current draw is consistent, and energy use can best be expressed accurately as µA. In calculating battery life, two different states of operation must be considered:

- Radio sleep current
- Battery self-discharge

Periodic events

Periodic events occur at various intervals during operation; thus their current draw cannot be measured directly as it can be with steady-state events. Instead, the total energy consumed during the event is measured in µC and then converted to average current based on the event frequency.

The following equation shows this calculation:

$$I(event\ average\ current)[\mu A] = \frac{((number\ of\ events) * (event\ energy\ [\mu C]))}{Time}$$

There are two types of periodic events:

- Ember EM357 radio transmissions
- Ember EM357 data polls

Sensor and radio parameters

Each security sensor has a sensor and a radio; both components have different parameters that affect battery life. These parameters are calculated in either current consumption or energy consumption; the differences will be explained later in this section. Table 1 summarizes the radio and sensor parameters determined by Ember and iControl.

Table 1: Radio and sensor parameters.

Parameter	Description	Type	Unit
Radio Parameters			
Radio sleep current	Steady-state current consumed when the radio is in an idle state	Steady-state operation	µA
Radio transmissions	Energy required to complete a data poll operation and transmit a data packet	Periodic event	µC
Data poll	Energy required to complete a data poll operation and transmit a data packet	Periodic event	µC
Sensor Parameters			
Sensor stand-by current	Steady-state current consumed by the sensor when idle	Steady-state operation	µA
Event energy	Amount of energy required by a given sensor to respond to a physical event (such as a door opening)	Periodic event	µC

Measurement units

Three measurement units are used to develop the sensor battery life calculations: µC, µA, and mAh. Per Table 1, radio and sensor events are expressed in either µA or µC, depending on whether steady-state current was being measured (µA) or the current associated with an event of a specific time interval was being determined (µC). The overall lithium battery capacity is expressed in mAh.

The events measured in coulombs can easily be converted to mAh. One coulomb (C) equals one amp second (As). A coulomb represents the number of electrons that flow through a circuit at one amp of current each second. For example, if each data poll is 200 µC, and the event happens one time per second, the average current is 200 µA.

Battery technology

Security sensors manufactured by iControl are powered by CR2 lithium batteries. To accurately calculate the battery life of a device powered by lithium batteries, both self-discharge and internal resistance must be accounted for. The total number of electrons that a

battery can move through a circuit is known as its capacity, measured in mAh. While this capacity is fixed, the battery life varies based on the operations the battery powers.

Self-discharge is a phenomenon in batteries in which internal chemical reactions reduce the stored charge of the battery without any connection between the electrodes. Self-discharge decreases the shelf-life of batteries and causes them to have less charge than expected when actually put to use. To model self-discharge, the team added a continuous self-discharge current of 3.24 µA.

Batteries are derated to account for internal resistance that becomes significant during radio operations. For example, the lithium batteries that iControl uses in its sensors are derated from 800 mAh to 600 mAh to account for internal resistance of the battery.

Battery operation primer: One way to look at energy consumption is to think of the battery as a tank of water, the volume of water representing the total capacity of energy available for use. Water is emptied through a pipe and faucet attached to the tank—flowing at a certain rate, which is similar to the current flow of a circuit drawing on the energy of a battery. Anything that can be done to reduce or interrupt this flow will extend the time that water remains in the tank (or energy remains in the battery).

Battery life calculations

The life of a security sensor battery is calculated by dividing the battery capacity (expressed in mAh) by the total average current (expressed in µA). This formula is shown below:

$$Battery\ Life\ [H] = \frac{Battery\ Capacity\ [mAh]}{Total\ Average\ Current\ [\mu A]}$$

The total average current is the key factor; it is a sum of all the events, both steady-state and periodic, and the battery self-discharge. This formula is shown below, where I represents current:

$$\begin{aligned} &I(total\ average\ current)[\mu A] \\ &\quad = I(steady\text{-}state\ operation\ average)[\mu A] \\ &\quad + I(periodic\ events\ average)[\mu A] \end{aligned}$$

The "Technical Background" section laid the groundwork for all the work devoted to measuring and calculating each of these variables. The following sections provide the actual values used in these formulas to determine the battery life for the contact sensors.

Contact sensor battery life calculations

As described above, the contact sensor battery life is calculated by dividing the battery capacity by the average current draw. While the battery capacity is easily estimated by derating the battery, the average current draw is obtained by summing all the steady-state and periodic events taking place by the radio and sensor. Here is a list of those events:

- Steady-state operation
  - Radio sleep current
  - Battery self-discharge
- Periodic events
  - Data poll
  - Radio transmission

The total average current equation is as follows:

$$\begin{aligned} &I(total\ average\ current) \\ &\quad = I(steady\text{-}state\ operation) + I(periodic\ events) \\ &\quad = I(radio\ sleep\ current) + I(battery\ self\text{-}discharge) \\ &\quad + I(data\ poll) + I(radio\ transmission) \end{aligned}$$

The total number of events per day was estimated to be 100. This value is defined by the application, but this variable could be adjusted to accommodate different security scenarios. Similarly, the data poll rate was set for once every 27 minutes, or 53 polls per day.

Table 2 shows each of these events and their corresponding values.

Table 2: Energy consumed by contact sensor components.

Operating Type	Parameter	Event Energy	Number of Events	Average Current
Steady-state	Radio sleep current	N/A	N/A	.65 µA
Steady-state	Battery self-discharge	N/A	N/A	3.42 µA
Periodic	Data poll	1944 µC	53/day	1.19 µA
Periodic	Radio transmission	1944 µC	100/day	2.25 µA

Using the values in the Table 2:

$$\begin{aligned} &I(total\ average\ current) \\ &\quad = I(radio\ sleep\ current) + I(battery\ self\text{-}discharge) \\ &\quad + I(data\ poll) + I(radio\ transmission) \\ &\quad = 0.65\ \mu A + 3.42\ \mu A + 1.19\ \mu A + 2.25\ \mu A = 7.51\ \mu A \end{aligned}$$

To calculate the battery life, apply this formula:

$$\begin{aligned} &Battery\ Life\ [H] \\ &= \frac{Battery\ Capacity\ [mAh]}{Total\ Average\ Current\ [\mu A]} \\ &= \frac{600\ mAh}{7.51\ \mu A} \\ &= 79{,}893\ hours \\ &= 9.12\ years \end{aligned}$$

Thus, Ember and iControl achieved the initial goal of obtaining more than three years of battery life for the contact sensor based on technology currently available to roll out to consumers.

Conclusion

Ember and iControl have partnered to develop sensors to enhance SMA Platform capabilities and to meet the requirements of broadband service providers. The results of this collaboration, as demonstrated in this white paper, provide sensor battery life spans well suited to the practical maintenance considerations in a typical home security environment.

Extended battery life is achieved by optimizing all parameters associated with current and energy consumption. Ember's product roadmap contains a variety of software optimizations aimed at improving battery life for all battery-powered ZigBee devices. Moving forward, Ember and iControl are committed to working together with the goal of achieving security sensor battery life in excess of ten years in the near future.

Further inquiries on the practical and technical considerations of deploying a full-featured home security system on an SMA Platform are welcome. For more information, contact either Ember or iControl directly.

Using Third-Party IP Protocol Stacks in M2M Designs

by Rick Bailey, *Multi-Tech Systems, Inc.*

Instead of requiring developers to write new control code for each new IP protocol stack, Multi-Tech's Universal IP is a single implementation that is applied uniformly across multiple modems that implement every major communications technology.

When TCP/IP functionality is employed in the embedded world, it is generally to enable machine-to-machine (M2M) communications. In many applications, such as fleet tracking and remote monitoring, the physical medium for the internet connection will be a cellular wireless network, but equally some embedded applications might access the internet via Wi-Fi or a wired Ethernet link.

The implementation of an internet-based M2M system will typically consist of, on one side, a chipset (baseband and transceiver) in which the baseband runs a version of the TCP/IP protocol stack; and on the other, an applications processor or microcontroller, which runs software to execute protocol commands via an applications programming interface (API).

Embedded developers are familiar with the pressure to reduce bill-of-materials cost and design risk on each individual project they work on. In the case of wireless internet-enabled systems, this can drive design teams to adopt an architecture that uses a cellular radio module (consisting of a cellular chipset, plus power circuitry and associated peripherals and interfaces), and to implement the protocol stack supplied by the chipset or module manufacturer. (Large chipset manufacturers include Qualcomm, ST-Ericsson Wireless and MediaTek. Module manufacturers include Cinterion and Sierra Wireless.)

When examined at the level of an individual project, this design approach might appear to make sense, but this conflicts with the common business model of small to medium-sized businesses (SMBs) in the embedded world. In reality, most embedded OEMs succeed by creating platform products on which they build extensions – product variants or modified versions of a base product – in three dimensions:

- Over time – during the typically long product lifecycles of embedded devices, updated variants are periodically developed to adapt to changes in the technical, regulatory or user environment.
- Over market segments – successful pioneer products in one market may be modified to suit the needs of adjacent markets. A fleet tracking device, for instance, might evolve a variant for container-tracking.
- Over geographies – a European product could be adapted for the U.S. market by replacing a GSM capability with CDMA.

On this model, profitability depends on maintaining a stable core platform, and re-using as much application code as possible across every product variant. Now, the scenario for implementing a protocol stack described above begins to look flawed. The problem arises when a new product variant requires a new protocol stack implementation – and this can happen in all three dimensions:

- Time – chipset manufacturers are driven by the short product lifecycles of handset manufacturers, not the large market windows that embedded OEMs address. Older chipsets are regularly made obsolete and replaced with new chipsets, and for each replacement the chipset supplier creates a new IP stack implementation.
- Market segments – a low-end product extension might require a cost-reduction from a high-speed connection to a low-speed connection. Replacing a high-specification module with a lower-cost alternative might entail implementing a new IP stack.
- Geographies – as above, different regions of the world run different cellular technologies. Replacing a GSM module with a CDMA module might again entail implementing a new cellular module with a new IP stack.

Each new IP stack will require developers to write new application code to control it. Development of this new application code potentially requires the designer to learn a new set of commands each time and to work out how to use a new API. Even if the embedded OEM uses the same module manufacturer across the whole of a product platform, the module manufacturer will not necessarily use the same chipset supplier across all modules. In any case, ensuring long-term consistency across all IP stack implementations is not a priority for the wireless chipset manufacturers, which are driven by the demands of the world's top handset manufacturers, not by the collective demands of tens of thousands of small to medium-sized embedded OEMs.

Some module manufacturers have developed proprietary TCP/IP stacks to replace those supplied by their chipset suppliers, and in the long term this might enable them to align the different stacks that support different communications standards, such as 2G and 3G, under a single API.

But it is still the case that, for the typical embedded OEM, rewriting application code to interface to new IP protocol stacks is both difficult and fails to add extra value to the end product. It is difficult because of the nature of the typical embedded business. Development at these embedded SMBs is carried out by small design teams with expertise in the hardware and software aspects of their core application – design functions such as sensor interfacing, signal conditioning and processing, microcontroller or microprocessor programming, application development, and user interface design. Communications system design and configuration is a peripheral element of the design, and mastering its complexities is difficult to do when it is not the main focus of the team's work.

The TCP/IP protocol stack implementations designed primarily for mobile handset OEMs are, then, ill suited to the needs of many embedded SMBs. These SMBs would be better served by a stack implementation that allows re-use of application code across all product variants, and that makes the writing of this application code simple in the first place.

An architecture developed by embedded modem manufacturer Multi-Tech Systems is aimed at delivering this to low and medium-volume manufacturers. Multi-Tech's Universal IP is a single implementation of the IP protocol stack that is applied uniformly across multiple modems which implement every major communications technology, from HSPA, GPRS and CDMA to Wi-Fi and Ethernet. Universal IP implements protocols including DNS resolve, FTP client, Ping, POP3 client, PPP (dial-out), SMTP client, TCP RAW client and server, UDP RAW client and server, PAP and CHAP authentication, as well as various additional communications functions aimed at M2M applications (Figure 1).

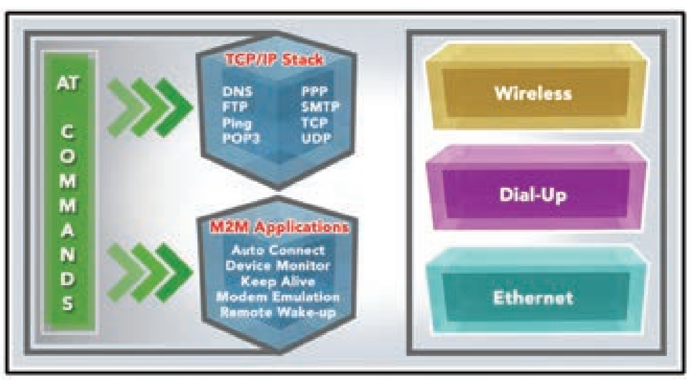


Figure 1: Multi-Tech's protocol stack implementation also supports additional functions aimed at M2M applications.

Each Universal IP modem also adopts the Universal Socket pinout (see Figure 2), which means that embedded developers can swap one modem for another without redesigning the board; they can also use the same application code to control the modem across all product variants.

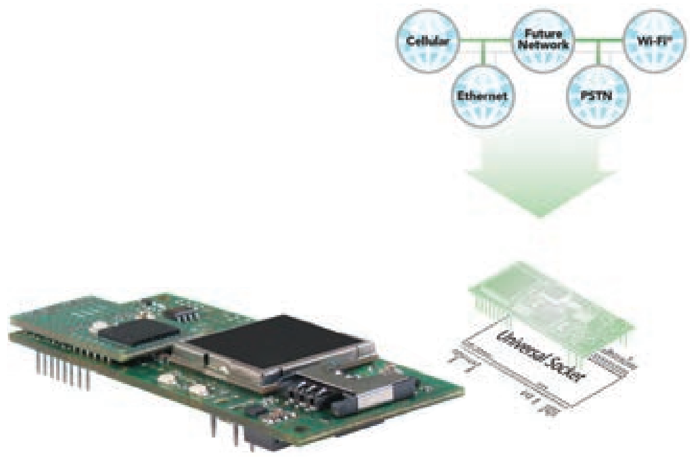


Figure 2: Multi-Tech Systems implements the Universal Socket pinout across all SocketModem devices such as this SocketModem iCell intelligent embedded cellular modem.

Moreover, Multi-Tech is committed to maintaining a stable Universal IP API over the long term. This means, for instance, that OEMs can remain blind to underlying chipset changes. Just like embedded users of cellular modules, Multi-Tech has to periodically redesign its modems when a chipset goes obsolete, but users of Multi-Tech modems see no difference, because the Universal IP API always stays the same, as does the Universal Socket pinout.

The Universal IP stack implementation depends on the hardware architecture of the modems: in a cellular chipset, the IP stack is hosted on the baseband, which is the proprietary design of the chipset manufacturer. When the baseband changes, so does the IP stack, and users cannot control it.

In Multi-Tech's Universal IP products, the protocol stack is hosted on a discrete processor, separate from the cellular chipset (see Figure 3). Since Multi-Tech has total control over the processor and the software it runs, it can ensure that its interface to the user's system controller remains stable over time and over a complete range of modems. The result is that the interface between the application and the internet is always Universal IP, not the moving target presented by the module manufacturers.

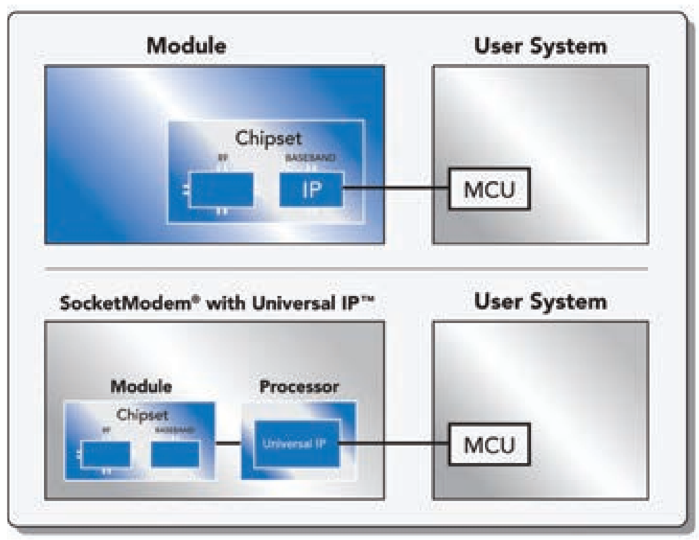


Figure 3: Basic architecture of a typical cellular module and architecture of a Multi-Tech modem with Universal IP showing the discrete processor hosting the IP stack.

The stack communicates with the user system over a serial interface. The operation of the stack is controlled through a set of simple AT commands that will be familiar to anyone who has designed with modems. In fact, this suggests two meanings to the word ‘universal’ in Universal IP: universal across all modems that run the Universal IP stack, but also universally applicable by embedded designers, since any microcontroller with a serial interface can issue AT commands, and the AT instruction set is (at least almost) universally recognized by embedded developers.

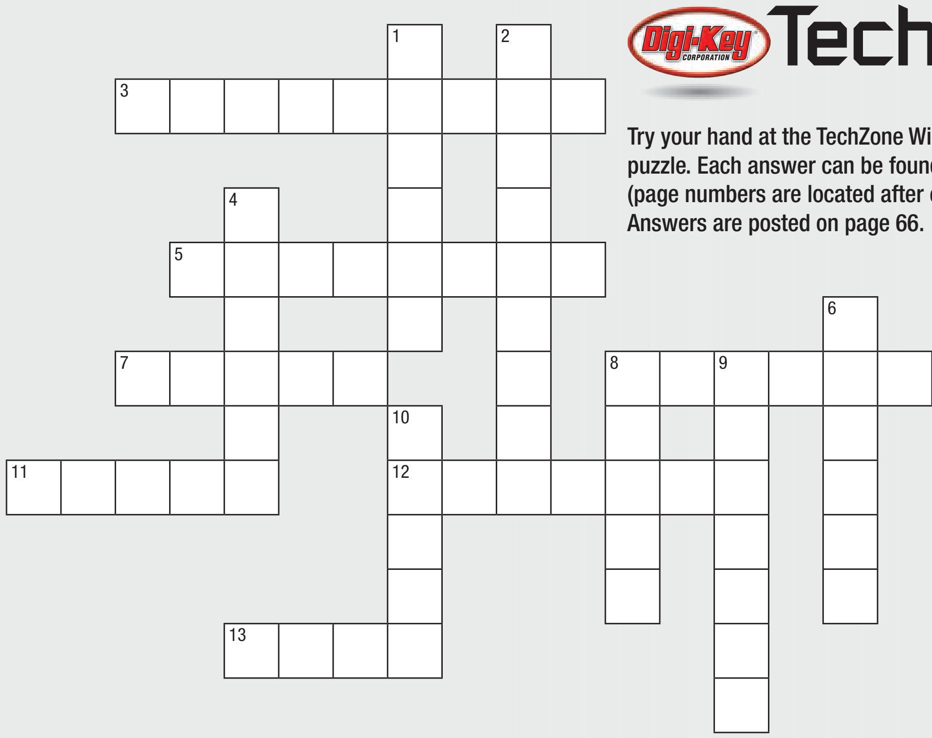
The architecture of Universal IP products, with their discrete processor, also enables Multi-Tech to implement an IP stack with features suited to embedded users. For instance, Multi-Tech implements an Auto-Connect function in its Universal IP modems; should the device drop off the network, it will automatically attempt to re-connect without human intervention. The stack can also be configured to periodically input traffic to a cellular network (the Keep Alive function). Some cellular network providers automatically disable devices that have been idle for a certain period of time, a practice that might make sense for handsets but is inappropriate for embedded devices. This function ensures that the network sees that the modem is still active.

Conclusion

The mobile handset is the world’s highest-volume OEM market, and the cellular chipset business is therefore skewed towards the needs of fewer than 20 global manufacturers.

By abstracting the IP stack out of the chipset and into a processor under its own control, Multi-Tech’s Universal IP provides a way to address the application needs and product lifecycles of the thousands of embedded OEMs that need devices to access the internet via cellular networks or other media.

TechZone Trivia



Try your hand at the TechZone Wireless crossword puzzle. Each answer can be found in this issue’s articles (page numbers are located after each clue). Answers are posted on page 66.

ACROSS

3 Coupling between the GSM and GPS radios and antennas, for example, may be _________ by mounting them on opposite sides of a PCB. *(pages 17-19)*
5 The ability to track data raises many ________ : energy data can be used to determine what people do in their houses (privacy) as well as whether or not they are currently home (security). *(pages 34-37)*
7 The 902MHz-928MHz band is highly favorable due to minimal _______ restrictions and excellent propagation characteristics. *(pages 50-56)*
8 Universal IP modems use the Universal _______ pinout so embedded developers can swap one modem for another with the same board layout. *(pages 29-31)*
11 For active tags, the requirement for battery life is _______ years (minimum) from a simple coin battery such as a CR2032. *(pages 48-49)*
12 “___________ load power” is the deciding factor in deciding if energy harvesting techniques can be used remote wireless sensor networks. *(pages 61-63)*
13 Another key requirement for smart meters is the use of high-performance yet low-power ______. *(pages 32-33)*

DOWN

1 Ember’s product roadmap contains a variety of software optimizations aimed at improving battery life for all battery-powered _________ devices. *(pages 26-28)*
2 The use of the AT86RF231 Antenna Diversity transmission _______ considerably improves the reliability of real-world network implementations. *(pages 20-24)*
4 The _____ PowerMeter and load-control services are two such examples, with many more such services becoming available every day. *(pages 41-43)*
6 A Bluetooth low energy unit can thereby offer a range of 200-300 _______ in line of site without the need of an additional power amplifier. *(pages 57-60)*
8 Devices are available that convert AMR device data to industry standard protocols like the ZigBee® _________ Energy Profile. *(pages 38-40)*
9 I am sure you are asking yourself - how come I used mobile phones that _____ violate these guidelines? *(pages 7-9)*
10 To meet the growing demand for cost-effective in-home control networks, NXP offers the TDA5051A, a highly integrated ASK modem that uses the existing _______ network as the communication channel. *(pages 44-46)*

Embedded Design Requirements for Smart Metering Systems

by Keith Odland, *Silicon Laboratories, Inc.*

Wireless transmitters, receivers and transceivers are becoming more common in metering systems. Smart meters involve some unique design challenges, as this article explains.

The notion of using technology and intelligent systems to enable the efficient use of energy and other resources has become a familiar 21st-century theme. The term "smart metering" jumps from the headlines of both mainstream and technical media every day. The general public often associates smart metering with intelligent electricity meters used to enable the Smart Grid. In reality, smart metering is also used to monitor other forms of energy usage such as natural gas and heat (i.e., thermal energy), as well as water, a vital resource around the world.

Metering information from residential, commercial and industrial facilities is typically sampled at regular intervals and aggregated by a common metering collector before being sent to the service provider. Unlike electricity meters, gas, water and heat meters are powered by batteries and have service life expectations of up to 20 years. This creates unique challenges for metering system designers who have to balance the limitations of current energy storage technology with the ever growing power consumption requirements of these more complex systems. New system architectures and power management strategies are evolving to meet these changing requirements.

There are three distinct categories of metering systems, each with its own unique requirements. The most common type is the electricity meter, which quantifies the consumption of electrical energy. The second most common is a meter that measures consumption of fluids such as water, natural gas or fuel oil. The third category – heat meters or heat cost allocators – quantifies the consumption of thermal energy.

Electricity metering systems comprise two functional areas: metrology (or measurement) and the communications subsystem. Metrology requirements vary by region and meter type (residential versus industrial). Key variables include the number of phases being measured, measurement accuracy, the requirement for different rates depending on time of use and the level of security required at the communication layer.

Electricity meters measure the electrical power consumed by a customer, the power factor of the load and the time of electricity consumption to support multi-rate metering. These measurements rely on various sensor technologies that match the number of electrical phases in the system. Consumer meters are typically single phase while commercial and industrial customers often use multiphase meters. These meters usually derive power from the mains but require an alternate supply such as a battery or super-capacitor to maintain a state in disconnect or disruption of service conditions.

Gas and water meters (Figure 1) are generally battery-powered systems that include a microcontroller (MCU) that interfaces to a metering sensor, display and communications block – typically a wireless transmitter or transceiver. These systems often use positive displacement flow meters to measure the number of times a unit volume of the fluid moves through the meter. For viscous fluids, volume is measured by a magnet or shaft that rotates. Each revolution is converted to an electrical signal and accumulated by the MCU. Less viscous fluids, such as natural gas, might rely on ultrasonic transducers to measure mass flow. Regardless of the material that is measured, low-power consumption is a critical design requirement in these metering systems, which typically are not wired to an electricity source.

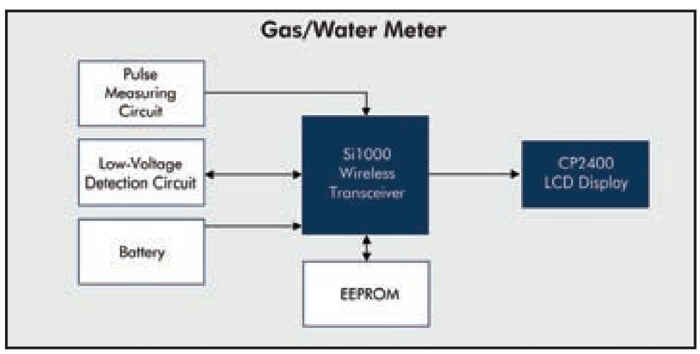


Figure 1: Example of a smart gas/water meter system based on the Si10xx wireless microcontroller, which includes a high-performance sub-GHz wireless transceiver.

Thermal energy meters (heat meters and heat cost allocators) are typically installed in multi-tenant buildings that rely on centralized heating systems. These meters measure the amount of heat being delivered to a location in a given period of time. Like gas/water meters, thermal energy meters are battery-operated systems optimized for the lowest overall system power. They also contain an MCU that measures the flow and temperature of the heating fluid

and incorporates a display and communications block. Heat is billed by the power delivered to the location measured by the heating fluid flow and the input and exit fluid temperatures over a given time period. This information appears on a display either integrated into the meter or remotely located and is transmitted over a wireless link to a collector, where it is aggregated and communicated to the service provider.

Metering functions and requirements

Each type of meter must provide one or more of the following functions:

- Quantitative measurement: The primary metering function is to accurately measure a quantity of energy or fluids. Measurement systems span a range of topologies and components including temperature sensors, flow sensors, shunt resistors, isolation transformers, current transformers and time-keeping systems.
- Control and calibration: These systems are used to compensate for small variations in the measurement system and to handle functions such as tamper resistance and interruption of service.
- Communications: Wired or wireless connections can be used to configure the meter's parameters and transfer stored data to a host, as well as to update metering firmware or other operational characteristics.
- Power management: Low-power and system robustness are essential in the event of power loss. In battery-powered metering systems, power management is critical to minimize power consumption and maximize battery life.
- Display: Low-cost, low-power LCD and LED displays in seven-segment, alphanumeric or matrix format are common user interfaces. Regulatory requirements often stipulate that customers must be able to view the billable quantity directly from the meter.
- Synchronization: Timing synchronization is critical for the reliable transmission of data to a central hub or other collector system to support functions such as data analysis and accurate billing. This is essential for a wireless network that has an unpredictable or asynchronous communication protocol.

In some applications and markets, meters are subject to stringent low-power requirements. For example, the service interval for an underground water meter is 20 years or more. For these applications, specialized lithium battery chemistries (such as lithium thionyl chloride or Li-SOCl2) with very low self-discharge rates are needed to meet the longevity requirement. These battery chemistries can be quite costly compared to mainstream battery types.

Another key requirement for smart meters is the use of high-performance yet low-power MCUs. Most metering systems require MCUs that consume very little power while offering an array of integrated features such as a real-time clock, analog-to-digital converter and communications interface. More advanced features such as integrated LCD controllers, a cyclic redundancy check block, or an encryption engine can reduce the MCU's processing burden, enabling it to reside in low-power modes for long periods of time and reducing overall system power.

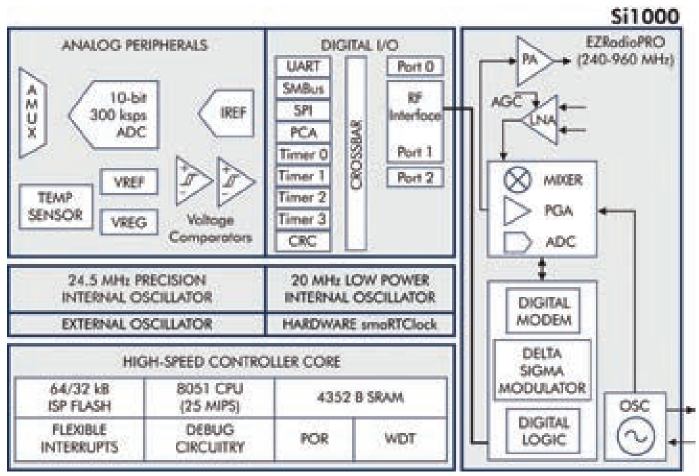


Figure 2: Silicon Labs' Si10xx wireless MCU provides a control and connectivity solution that combines an ultra-low-power MCU core with a sub-GHz wireless transceiver.

Wireless transmitters, receivers and transceivers are becoming more common in metering systems. Key features include high levels of integration, very low-power operation, fast start-up from low-power states, high receiver sensitivity (greater than -118 dBm) and high transmit powers without external power amplifiers (up to 20 dBm). More advanced features include automatic packet handling, integrated FIFO and variable frequency and modulation schemes.

Wireless MCUs (see Figure 2) that combine the MCU with a wireless transceiver are also available for smart meter applications. These highly integrated single-chip devices can help reduce BOM and system cost while providing a low-power embedded control solution capable of high-performance wireless connectivity.

Other key technologies for next-generation metering systems are wired access products such as modems for line-based data communication, timing solutions for network synchronization and CMOS-based digital isolation products for safety and compliance of electrical meters.

As more embedded intelligence is integrated into smart meters, we'll see an explosion of innovative applications and additional opportunities to harness the advanced capabilities these intelligent systems will bring to energy and resource consumers everywhere.

Did You Know?

There are no standard protocols for meter-to-meter and meter-to-infrastructure communications. Currently, the available communication media includes:

- power line communication
- GPRS
- 400 Mhz metro-area networks
- 3G
- WiFi

More likely, however, a multi-media network will have a mesh of these technologies in it.

Designing Intelligent Appliances for the Smart Grid

by Nicholas Cravotta

The Smart Grid promises to be a game changer, but the rules of the new game are still being written. The burgeoning Smart Grid infrastructure promises to reduce costs and enable a wide range of innovative consumer, industrial, and embedded devices.

The Smart Grid promises to be a game-changer across the entire electronics industry, including consumer, industrial, and embedded devices of all types. Innovation is driven by value, either because a new product reduces the cost of an existing technology or because it offers new features and capabilities that users are willing to pay for. While it isn't always predictable whether consumers will be willing to pay a premium for new features, the prospect of reduced operating cost is always attractive.

Consider the lighting automation industry. Controlling every light in a house remotely has been possible for over a decade. High-end systems offer features every consumer would love to have, just not at a price most can afford or are willing to pay. X10 technology provided a cost-effective approach to lighting automation, but its unreliability has left consumers unexcited. As a result, the home lighting automation market has experienced limited growth.

With the development of Smart Grid technology, the focus is first and foremost on enabling significant cost savings by intelligently monitoring and managing power consumption. For a few dollars more, appliances will be able to accurately measure power consumption and turn themselves on and off based on power availability and time-based pricing tiers. As the Smart Grid is deployed, however, it will also bring with it an infrastructure that will readily support a wide range of automation capabilities.

The best candidates for intelligent power management are those appliances which consume a lot of power and are fairly discretionary as to when they are used. The primary consumer of power within the home and business is typically the HVAC (Heating Ventilation A/C) system, followed by appliances with motors and power supplies such as washers and dryers. Items like refrigerators and stoves may consume power but are not discretionary in their use, so the need for them to be smart is much less pertinent.

Other key trends driving the adoption of Smart Grid technologies include:

- **More efficient management of power on the grid:** Power capacity continues to be outpaced by increases in power consumption. Building new power sources is extremely expensive and something the utility companies want to postpone for as long as possible. The alternative is to better manage the peak power load. This can be accomplished through various load shedding and demand response programs; for example, today consumers receive a rebate or price break if they allow their utility company to control their thermostat during peak usage times.
- **Bringing power awareness to consumers through visibility:** For most people, power consumption is a single number that arrives once a month in the mail. It is difficult to attempt to be more responsible with one's usage when one has no idea when or how power is being used. By providing real-time visibility into home and business usage patterns, consumers can actively analyze and reduce their consumption.
- **Enabling appliances to monitor their usage and support remote management:** For consumers to have access to energy information, it first has to be collected. While many power meters now track usage and time-of-day, they can only see aggregate power consumption (see Figure 1). As particular appliances are not being tracked, a consumer cannot tell if a usage spike is coming from a refrigerator, hot tub, dryer, or A/C unit.

Figure 1: With no spinning wheel, smart meters can track usage and time-of-day. However, they are limited to measuring only aggregate power usage unless appliances support intelligent power tracking and self-monitoring.

- **Sharing of energy information throughout the home and beyond:** When users can track power usage throughout their home, they can make wiser choices (i.e., shift time of usage to when lower pricing tiers are in place). Two primary hurdles exist: how to share information throughout the home and how to get this information out onto the Internet cloud.
- **Managing the increasing load as electric vehicles come onto the grid:** Electric vehicles require a great deal of power, and most drivers will plug their cars in when they return home from work. The problem is one on the neighborhood level: the presence of several vehicles simultaneously charging on the same transformer could create many problems for the utility companies. Rather than upgrade equipment, charging load can be spread across the evening when usage tends to be lowest.

Tracking and self-monitoring

Accurately tracking power usage and patterns requires that energy consumption be measured at the appliance itself. Metrology ICs step down appliance current to measure energy consumption and provide this information to the appliance's main processor. One of the primary cost drivers of metrology devices is how much accuracy is required. For some devices, like the smart meter itself, dynamic range impacts accuracy and so a higher resolution ADC is needed. For systems that operate within a well-defined range, a lower resolution ADC may be sufficient.

One side benefit of self-monitoring is the ability to profile appliance operation. With enough accuracy, an appliance can identify that it is exhibiting degraded behavior and alert the owner that servicing is required to avoid system failure. Major Smart Grid players such as Microchip, STMicroelectronics, and Texas Instruments offer a variety of metrology ICs to support their extensive offerings of Smart Grid components. ICs start at $1 for low-end applications and can run up to $20 for higher current and precision applications.

To improve efficiency, appliances also need to support demand response events and actively assist consumers in making usage choices based on tiered rates. Traditionally, the home HVAC system must be adjusted manually to reflect pricing tiers. When the thermostat is connected to a smart meter, it becomes possible to download real-time rate schedules and adjust usage automatically. When peak demand is high, the thermostat can be adjusted to a higher temperature and even turned off directly by the utility companies. Note that appliances such as refrigerators, communication devices (phones, routers, computers), and especially medical equipment cannot be arbitrarily shut down. Only devices that are connected to the Smart Grid can be managed in this way.

Self-monitoring also enables more granular control. Rather than supporting only control of weekday or weekend settings to keep programming complexity low, smart thermostats (see Figure 2) can allow consumers to program more complex schedules or even analyze power usage to determine if someone is currently in the house or building.

Figure 2: Smart thermostats allow intelligent management of heating and air conditioning systems, such as allowing utility companies to adjust usage during peak demand periods.

Designers also need to take into account the fact that some appliances need to be managed with more grace than simply being shut down. For example, consider a washer that is shut down mid-cycle as part of a demand response event. Unless the meter can also tell the washer to turn itself back on, the clothes will sit in water for hours. Preferably, the washer could drain before shutting off. The washer should also have a bleach indicator so that the washer can decline to shut down to prevent clothes from being destroyed in the hours it takes a consumer to return home. Alternatively, a person may be cleaning a shirt for an important meeting and needs to be able to override the demand response mechanism. These are the sorts of issues manufacturers need to anticipate.

Connection

Part of the philosophy behind tracking power usage in real-time is to increase consumer awareness of consumption, both by amount and by time-of-day. The current billing system provides consumers with a single consumption number, once a month, making it difficult to identify even simple inefficiencies such as a stereo left on or a parasitic wall charger that uses power even when it isn't charging. Real-time tracking allows consumers to uncover such energy drains by profiling the use of major power appliances in the home. If the total unaccounted for usage – i.e., all of the other appliances and electronics in the house – is high, this will alert consumers to potential areas for improvement through a change in usage habits.

To provide remote access and other automation features, appliances need to have a link to the home network and out to the Internet. Candidates to serve as the home network gateway include the smart meter, a separately purchased energy monitor, or the thermostat (because it is already connected to the largest power consuming appliance in the home).

The home network requires a connectivity technology that is inexpensive, simple to use, scalable, and power efficient. Those most commonly associated with Smart Grid applications include:

ZigBee: ZigBee has positioned itself as the defacto smart meter standard, claiming to be present in an overwhelming majority of deployed smart meters. Offering its Smart Energy and Home Automation Profiles which define how appliances communicate to the meter and each other (see Figure 3), ZigBee simplifies integration into the home network.

Figure 3: ZigBee's Smart Energy Profile provides an efficient way of connecting appliances within the home through the smart meter and allowing consolidation of energy data by utility companies.

Wi-Fi: As a wireless technology, Wi-Fi has a huge installed based, is readily available in most homes as an Internet connection, and is familiar to consumers. Connecting to a Wi-Fi-enabled appliance is about as complicated as configuring a wireless printer. In some circles, however, this is thought to be too complicated and a technology is desired that requires no configuration.

Powerline Communications (PLC): PLC provides a wired connection for appliances. Since it runs over powerlines, all major appliances are already connected to the smart meter.

Proprietary: Proprietary wireless connections tend to support automatic configuration and can be less risky to introduce to market. However, they require more hardware, cost more than standard technologies, and tend to have limited extensibility.

From a technology perspective, there is no obvious winning technology. Many of today's silicon vendors offer a variety of connectivity interfaces off-the-shelf. All of the required software, hardware, and features (such as encryption) are available. These vendors don't support one standard over another because they sell several of them. Depending upon the protocols, developers can even migrate between interfaces with minimal changes to system design. This allows manufacturers to support different connectivity options based on the cost and complexity the end product can tolerate.

There is also a good likelihood that all of these technologies will serve in the same home or business to connect the variety of appliances. ZigBee appears to have a clear lead from being integrated into many smart meter architectures. However, there are concerns that there may be appliances which are too far from the meter or another ZigBee node for reliable connectivity. PLC, in contrast, guarantees a connection. A likely scenario is to have ZigBee and PLC PHYs in the meter.

Access to the meter, however, is proving to be a tremendous challenge for appliances manufacturers. This is because of the great variety of implementations used throughout each country. Utility companies use different types of meter and require a different set of APIs to connect with them. In addition, many utility companies have yet to activate and open their communications link for use by appliances, thus preventing the meter from being used as the energy gateway. While independent energy gateways are available, these too support a wide range of protocols. From this perspective, the wariness of manufacturers to integrate Smart Grid technology into their appliances is understandable since there is no clear target yet at which to aim. Most appliances have an extended lifetime, and providing a dead-end implementation can damage a brand.

Regardless of the technology used, appliances will need to be able to operate when connectivity is disrupted. Ideally, appliances will track time on their own and be able to call up the last energy rate profile received. They may also be able to forecast demand response events to warn users during potentially expensive time slots. These are important considerations as well since it is the appliance manufacturers who will be held responsible for the robustness of energy management systems.

Consolidation

One of the major design considerations for utilities and manufacturers is managing and consolidating the flow of energy information. Moving from a single data point per month to several data points per half hour represents a tremendous amount of data to collect and correlate. As more appliances incorporate displays, they will be able to provide an accounting of their own consumption. However, much of the value of energy tracking comes from being able to coordinate all of the appliances in a home or business from a central point. While a thermostat, smart meter, or central energy monitor can serve as the data gateway for connected appliances, these devices may have limited display capabilities that prevent them from effectively conveying information about all of the devices within a home.

One approach is to support access to a PC or smart phone which can provide full configuration and UI functionality over a wireless link. Ideally, consumers would like to have remote access to energy information, requiring that information be passed out to the Internet cloud. This approach, however, requires that information be collected on a back-end server. Supporting such a server potentially introduces additional complexity and expense to appliance design. In addition, to be the most useful to consumers, energy information for the entire home needs to consolidated onto a single management platform so that consumers don't have to manually track individual devices. Consolidating energy savings is also likely to improve consumer responsiveness to energy conservation. For example, a dryer stating that it saves $5/month may not impress consumers as much as seeing that overall home savings are $40/month.

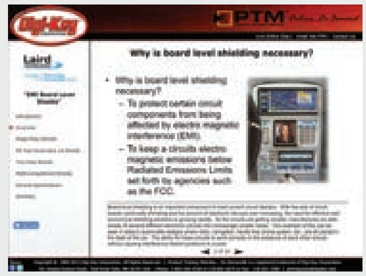
Some utility and energy monitor companies have chosen to use Google PowerMeter as an alternative to investing in building their own energy management platform. Google PowerMeter supports consumers and businesses either directly through their utility company or through a gateway device that can be purchased separately. As a standardized platform, Google PowerMeter will potentially facilitate a smoother transition to consumer energy awareness by providing a common and readily available API upon which to base smart energy designs. It also eliminates the need for utility or appliance companies to develop their own proprietary management platform.

The ability to track data raises many concerns: energy data can be used to determine what people do in their houses (privacy) as well as whether or not they are currently home (security). One of the more sticky issues yet to be resolved is who owns energy consumption data once it has been collected. Within the home, the meter or energy monitor can use standard security protocols and certificates to protect home network communications. Similar mechanisms will need to be in place between the gateway and back-end management platform. To support security, appliances will also need a simple and intuitive way to pair to the energy gateway. Pairing can be done through the use of a PIN provided by the gateway which is typed in on the appliance.

Smart Grid technology is still in its early stages. Fortunately, the base technologies required to implement intelligent energy management are themselves mature and already proven in the market. The challenge for manufacturers lies in determining which technologies to integrate and when to release them. Already products are coming to market that support energy awareness and as appliance manufacturers continue their trials and testing, more shall be added to store floors. With the advantages of intelligent energy management so high, especially with the promise of increased automation capabilities, it shouldn't be long before the details of how to connect appliances are clear.

EMI Board Level Shields

Laird Technologies



Laird Technologies' EMI board level shields provide the shielding necessary for differing circuits to operate amongst each other, all in a basic metal shell that mounts over single or multiple components. The devices offer the necessary shielding while adding only a minimal amount of height and weight to a circuit board.

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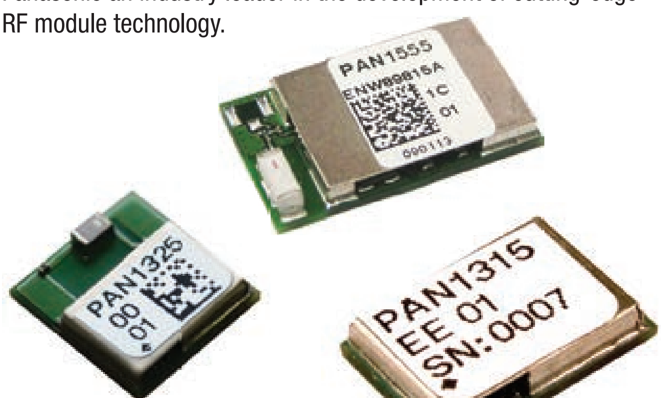
Panasonic Electronic Components provides powerful, highly flexible, cost-effective RF modules for a wide variety of wireless Personal Area Network (PAN) applications. New extended range products and small footprints combined with network firmware flexibility make Panasonic an industry leader in the development of cutting-edge RF module technology.



POWERED BY Panasonic Electronic Components

Features

Reduced Design Cycle. Get your wireless products to market faster by greatly reducing the design-to-production path. RF hardware design, development, debugging and test, board layout, quality testing and certifications are all removed by choosing a Panasonic RF module.

Extended Product Life Cycle. RF modules provide a constant footprint and pin out over several generations of integrated circuits to guard against the need to re-spin or redesign a wireless product to accommodate an IC that is no longer available. RF modules extend the product life cycle of any wireless product .

New Revolutionary Software Alternatives. The time or software resources required to learn network stacks and develop applications is daunting and expensive. Panasonic has partnered with several software developers for all of the major network protocols, including Bluetooth®. From fully developed Bluetooth profiles to flexible AT commands, Panasonic can deliver an RF module with the firmware needed to make any project a success.

Wireless Solutions For Less. RF modules can reduce the total cost of ownership for product development projects up to 50,000 units per year. Designing in an RF module rather than a discrete wireless solution can reduce expensive development, test, certification and production resource requirements.

New Bluetooth RF Modules. Bluetooth, which is based on IEEE 802.15.1, was developed for the purpose of sending larger amounts of data quickly from computers to PDAs to cell phones or other portable handheld devices. Key features include high data rate, frequency hopping, very small form factor and modest power consumption. Panasonic offers a new Bluetooth RF module product line that makes connectivity between mobile devices such as cellular phones and small button cell battery powered devices like fitness sensors, watches, health care, entertainment and mobile accessories easily implemented, creating a seamless data chain from sensors to the Web.

www.digikey.ca/panasonic-wireless

Merging Legacy Systems and the Smart Grid

by Dave Mayne, *Digi International*

It is becoming increasingly clear that the Smart Grid is not defined by NEW devices, but rather by the services enabled by adding secure and reliable two-way communications to as many points on the distribution grid as possible.

The Smart Grid is a term that is now recognized by a broad range of people that have never worked at a utility or related business. There are stock indices following businesses developing products and services that enhance the grid, continual legislation focused on investment and research in energy generation and distribution, and an increasing recognition that the way people view and manage their energy usage in the future will be dramatically different from today. These factors are driving many analysts to predict more than $200 billion will be invested in new grid technologies between 2008 and 2013, with over $53 billion in the U.S. alone (source: Pike Research).

These new investments cover a broad range of products and services, but virtually all are focused on enabling enhanced monitoring and control across the electrical distribution network. This includes capturing more granular information related to power quality, consumption, and grid performance by facilitating two-way communication and generation capabilities throughout the distribution system.

It is becoming increasingly clear that the Smart Grid is not defined by NEW devices, but by the services enabled by adding secure and reliable two-way communications to as many points on the distribution grid as possible. Clearly this will require some new equipment, but it will also require innovation that minimizes stranded assets for the utility industry.

Digi International has identified four capabilities (Figure 1) that are required to drive the benefit goals of the Smart Grid:

- Create: devices and sensors to capture information and provide control services
- Collect: communication devices and networks that allow data and control services to happen
- Manage: a network operating environment for managing all the connected devices
- Utilize: business applications that turn the data into actionable information and driving benefits

Figure 1: Capabilities required for a successful Smart Grid.

In reviewing these capabilities, several interesting observations can be made. The first is that these do not define a specific network technology, device, or sensor. They are a capability that must be enabled for all devices (new and old) that are part of the energy distribution framework. These capabilities will need to exist for devices in the substation, down the feeders, at the metering points, and even into the extended grid inside a home or business.

A second observation is that the value is not defined by the device, but rather by the business application utilizing this communication and control capability. In other words – these capabilities drive benefits whether this is a new asset or an investment that was made five years ago. The benefits are almost universally defined by business functions rather than the device itself. Once this is recognized, it is much easier to evaluate technology gaps that need to be filled. These gaps tend not to be specific devices or protocol, but rather a machine-to-machine management platform that can easily connect these devices to the appropriate business applications. Making the right decisions at this level will drive accelerated deployments of Smart Grid technologies that can leverage distribution equipment both new and old.

As stated earlier, it is estimated that over $200 billion will be invested globally in the Smart Grid by 2013, but the existing grid assets far exceed this number. Is it possible to enhance these solutions to make them more viable in supporting bi-directional communications, control and generation services? Can the utility (and rate payers) achieve an

Figure 2: Value derives from business functions, not devices.

adequate percentage of projected Smart Grid investment benefits without replacing the current asset? There are a growing number of communication companies trying to address these questions in an effort to accelerate deployment of Smart Grid services, and service the widely varying business case drivers being presented by utilities large and small.

Smarter AMR with consumer engagement

The industry is closely watching the early adopters of Smart Metering technology, with several utilities now announcing deployments exceeding one million units. While this progress is impressive, there are nearly 150 million meters that are already automated with AMR communication technology. Clearly these devices do not provide all of the interval data collection, remote disconnect capabilities, or other enhanced communication services that are envisioned for the final Smart Grid deployment. But it is possible today to add communications over public networks (cellular, broadband, etc.) that deliver consumer engagement/Energy management services with full HAN support. These capabilities allow utilities to deliver a broad range of demand-side services to their customers leveraging the existing metering investment.

Digi International, for example, recently launched a series of ERT gateways enabling the owners of over 40 million ERT meters to communicate over IP networking solutions. This allows utilities to

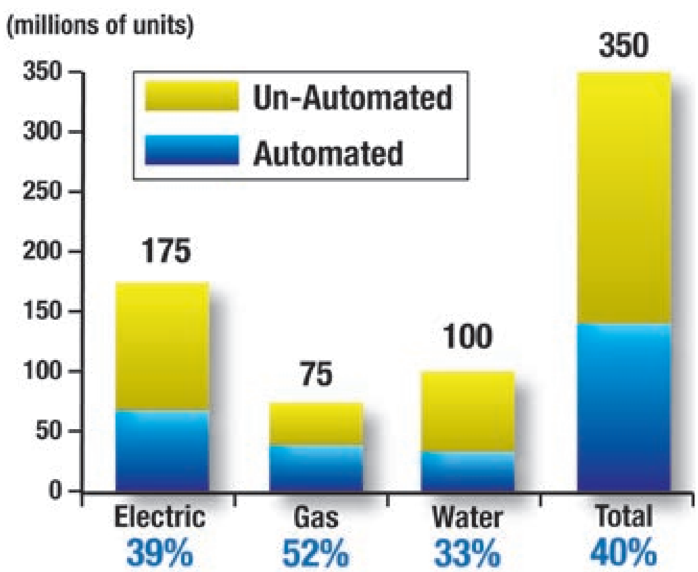


Figure 3: North American AMR Penetration (Source: IMS Meter Report 2007 Edition).

leverage their existing metering assets to provide customer energy management services, verified demand response measurements, or view coincidental load across a set of meters for load forecasting purposes. While this clearly is not a Smart Metering platform, it does facilitate a suite of services consistent with many Smart Grid business cases.

In addition, products are available that convert these AMR devices to industry standard protocols such as the ZigBee Smart Energy Profile. This minimizes stranded asset risk by connecting these ERT modules to a wide range of certified Smart Energy devices, presenting a smooth migration from the world of AMR to the Smart Grid.

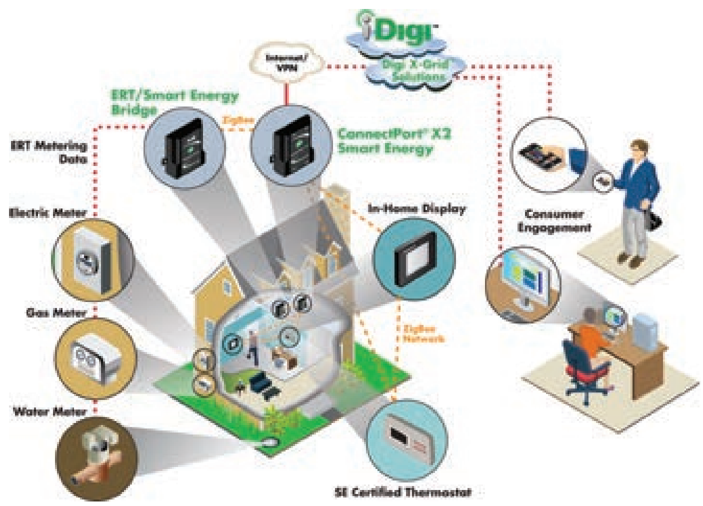


Figure 4: Consumer engagement with Smart Energy devices.

The industry will continue to develop and expand the use cases enabled by these new technologies, but providing tools that can provide flexible deployments that can future-proof the distribution grid are essential in driving early technology adoption. These AMR gateways are made possible by leveraging machine-to-machine management services that connect the utilities applications (consumer energy management portal, Demand Response platform, etc.) with their customers metering device – a key development in making this technology commercially viable.

Responding to network and other technology changes

On February 18, 2008 the Advanced Mobile Phone System (AMPS), better known as the analog cellular network, was no longer required to be supported by the carriers. This change forced the industry to figure out new methods of communicating with thousands of metering and distribution devices – most deployed at commercial utility customers across North America. The industry did not respond with a singular approach to this issue, but rather architected innovative solutions that met the needs of their respective business. For some utilities, this helped accelerate Smart Grid deployments – while others worked hard to avoid any meter change-outs by identifying technologies that could IP enable dial-up modems.

These decisions were not made based on the best technology, but rather based on the business drivers. This is true for Smart Grid deployments as well. There is not (nor will there be) a single software or communication solution that works for all utility business functions. The reality is that many communication

solutions – public, private, wired and wireless – all can and will contribute to the overall Smart Grid ecosystem. Each technology provides a unique set of performance, cost, reliability, and security goals that differentiate, but do not diminish their contribution to the overall system.

The challenge for the industry is not in identifying the communication solutions required, but in developing efficient, secure, and scalable connectivity over a broad range of networks. This "middleware" management platform will be a critical piece of the Smart Grid, and must not only provide support for the new technologies, but also manage devices and technologies that are already deployed. Most importantly, many M2M management platforms isolate the utilities' applications from the specific communication network allowing new technologies to be deployed without disrupting existing systems.

Conclusion – device management is key to being future proof

The combined forces of all networking technology utilized in the Smart Grid are aimed at time-sensitive collection of energy consumption data. Whether utilizing power-line carrier, fiber, cellular, or proprietary wireless communications, the goal is to determine what energy is being used, and more importantly, when! If I commute to the office during rush hour, I use far more gas than in the middle of the day; hence my costs (environmental and economical) are much higher than if I try to shift my driving patterns. The same is true for energy consumption. If I use electricity during the "electrical rush hour," the cost to the utility is significantly higher – yet in most cases they are unable to pass that extra cost on to the consumer.

The Smart Grid is the first broad reaching initiative enabling utilities to better map costs to price, which in turn will strengthen support and adoption of time-based rate structures. This will greatly increase the need for "energy dashboard" tools communicating rate and consumption data to consumers, and will rapidly expand the number of people actively participating in load shifting programs.

Once again, these challenges do not define a specific networking technology – but rather an information and control ecosystem that will utilize many networks – both wired and wireless – to promote an interactive, reliable, and efficient energy delivery grid. Selecting a software service that allows your applications to operate independent from the communication network will maximize the utility's ability to leverage existing assets while helping to future-proof the investments.

WiFi Authentication

Rabbit Semiconductor

Rabbit Semiconductor's guide to WiFi authentication is a self-paced tool to introduce design engineers to update program firmware via a secure wireless connection.

The product training module allows deign engineers to learn about new features of Dynamic C v10.54 release, recognize security terminology, protocols, and standards for WiFi authentication, and to understand remote program update firmware, and tools and sample programs used to implement features.

The module is 14 pages in length and can be viewed with or without audio in ten minutes.

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Did You Know?

Actress Hedy Lamarr and composer George Antheil together patented frequency hopping technology in 1942 that was the basis for modern spread-spectrum communication technology used in WiFi and in some cordless and wireless telephones.

Microcontrollers and Wireless Connectivity in Smart Appliances

by Derrick Lattibeaudiere and Abhinay Venuturumilli, *Microchip Technology Inc.*

Wireless connectivity is enabling smarter appliances that can communicate with other devices throughout the home and over the Internet. Choose the right wireless protocol and you're off to a good start.

The days of the drab household appliance that sits mostly idle in the corner of a kitchen or bathroom have come to an end. Today's appliances are sleek, functional designs that are innovative and form the centerpieces of most modern-day homes. One of the technological trends in appliance design that has gained a significant foothold in recent years is the smart appliance. These devices sport leading-edge technologies, including the ability to communicate wirelessly with other devices throughout the home and over the Web.

Smart appliance manufacturers see tremendous economic opportunities in directly communicating not only with appliances in the field, but also with the users of those appliances. Services such as remote diagnostics and firmware upgrades can be made more seamless to the user. Consumers also stand to gain economically, by removing the cost and obstacle of rewiring their homes through wireless connectivity.

In today's marketplace, green applications for smart appliances have begun to emerge that are centered around energy usage and monitoring. Services such as Google PowerMeter (see www.microchip.com/Google) have enabled consumers to gain instant access to their energy usage data. In turn, having this information has provided consumers with the impetus to undertake measures such as signing up for cost-saving energy usage plans that are offered by their utility companies. Utility companies are rapidly deploying wireless-enabled smart meters that connect to Home Area Networks (HANs), which allow them to provide load-control features to the smart appliances. The benefits are that the utility companies can better regulate their energy demands, collect valuable real-time usage data, and offer more suitable tiers of services to their customers. Using all this information, utility companies can more precisely predict and plan their future infrastructure expansion.

Manufacturers are able to bring wirelessly enabled smart appliances quickly to the marketplace by integrating two key building blocks into their products – wireless technology and advanced microcontrollers.

Figure 1: A smart home.

Additionally, large groups of technology companies have recently joined forces to form consortiums that have defined the framework of how these smart wireless appliances communicate with each other. The net effect of these developments has been the unleashing of design innovations within the application space of smart appliances. We are rapidly approaching the time when it will be commonplace to live in an affordable smart home with its many smart appliances, all wirelessly connected, as depicted in Figure 1.

However, these innovations are not without many design challenges. This article will discuss some of these challenges, and the trade-offs that are involved when choosing among the technologies that are used in a smart appliance. It begins with the choice of which wireless protocol to use.

Wireless technology choices

In terms of wireless networking protocols, the smart appliance manufacturer has a number of viable options to choose from. Some of the choices include Embedded Wi-Fi, ZigBee and proprietary protocols such as Microchip's MiWi Development Environment.

Wi-Fi is the most widely used wireless protocol. It is the wireless equivalent of the wired Ethernet protocol that forms the backbone of today's internet. Typically, Wi-Fi operates on high performance computers, which can handle data-intensive applications. Compared to traditional Wi-Fi, Embedded Wi-Fi performs a single or very limited number of functions, such as transmitting static images, but at relatively lower data rates.

Embedded Wi-Fi offers clear advantages in that any Wi-Fi enabled smart appliance is able to readily communicate over the Web. Typical data rates of 1-5 Mbps are supported, which make it suitable for control and monitoring applications. Embedded Wi-Fi operates in the universally available 2.4 GHz spectrum. This spectrum is an open and unlicensed frequency band and, as a consequence, is being used by other wireless technologies.

Another wireless option available to manufacturers is ZigBee. While Embedded Wi-Fi operates at data rates on the order of Mbps, ZigBee has a specified maximum data rate of 250 kbps, per the IEEE 802.15.4 radio standard. ZigBee positions itself as the low-power and low-data-rate wireless protocol of choice for wireless sensor networks. ZigBee-enabled smart appliances can be made to operate with extremely low-power, while utilizing inexpensive microcontrollers such as Microchip's PIC microcontrollers with eXtreme Low Power (XLP) technology. Other ZigBee strengths include its strong data security model, interoperability, and its expanding adoption across many application segments. Similar to Wi-Fi, ZigBee operates within the 2.4 GHz frequency band, utilizing sixteen defined channels, giving it flexibility in terms of channel hopping and frequency agility, in order to avoid noise and interference. As evidenced by its partnerships with both the Wi-Fi Alliance and HomePlug Consortium, the ZigBee Alliance is continuing to strengthen its interoperability credentials. ZigBee, along with Wi-Fi, have gained acceptance as viable networking technologies of choice for the U.S.-based SmartGrid Alliance.

Figure 2: Microchip's FCC/ETSI Certified IEEE 802.15.4/ZigBee Module and an XLP PIC microcontroller.

Another option available to smart appliance manufacturers is the use of a proprietary wireless protocol, such as Microchip's MiWi Development Environment. Proprietary protocols offer many advantages, including ease in customization for specific target applications; shortened development times when compared against open-standard protocols; less complexity; and ease of deployment. They also offer many opportunities for both innovation and IP creation. There is no need for the specialized certification that is often required by the open-standard protocols, which can bring a significant cost savings. Additionally, all of this adds up to a quicker time-to-market with a potentially lower cost device. However, the lack of interoperability with other manufacturers' products could result in a narrower market segment for the device, or require the development of a gateway device to translate to other wireless networks.

You can check the feature comparison for the three wireless technologies discussed in this article in Table 1.

Table 1: Feature comparison among the three major wireless technologies for smart appliances.

	Open Standard	**Software Complexity**	**Data Rate**
Wi-Fi	Yes	High	1-5 Mbps
ZigBee	Yes	Medium	250 kbps
Proprietary	No	Low	Variable

Data security

Network data security is of primary importance, because of the sensitive nature of the information that may be transmitted between devices. Security for both Wi-Fi and ZigBee is based on a robust AES-128 algorithm, and operates within the framework that is described in the IEEE 802.11 and IEEE 802.15.4 specifications, respectively. The methodology for establishing and transporting security keys, and the authentication of devices are all defined by each of the specifications. Smart appliance manufacturers who choose a proprietary wireless protocol have the added challenge of selecting the appropriate security algorithm and services.

Independent of the encryption algorithm chosen, there are two important security-related factors that each manufacturer must be aware of. The first is whether the encryption algorithm is subject to export control laws. Products containing software or hardware algorithms must either restrict their key lengths or obtain specific export authorizations. Regardless of whether they are based in hardware or software, encryption algorithms have the same restrictions and must adhere to all export control laws. Secondly, regardless of the robustness of the encryption algorithm, data integrity will be severely compromised if the keys are compromised. Therefore, protection of the keys themselves is of vital importance. Device manufacturers should devise an appropriate method of key protection.

The smart appliance platform

Wireless smart appliances are generally built upon a platform that includes three major subsystems: the microcontroller, which acts as the brain of the appliance; the wireless protocol stack, which defines the logical connections amongst devices in a network; and the RF transceiver, which handles the transmission of packets over the air.

Today's manufacturers have a wide selection of microcontrollers around which to design their smart appliance platforms. One of the major selection criteria is the cost of the microcontroller. Additional criteria are the size of its program and data memory, its power consumption, the availability of peripherals, and its processing speed.

Another important subsystem of the smart appliance platform is the wireless protocol stack. Its operation determines how the devices communicate, how many devices may be on a single

Home Area Network (HAN), and the maximum data throughput. The protocol stack is often the most complex software module in the application firmware. The development time of the smart appliance can be greatly reduced, if software for the stack is already available. Moreover, the portability of a vendor's stack across all of its microcontroller families is of primary importance. This gives the developer the flexibility to choose the 8-, 16- or 32-bit microcontroller that is most appropriate for a given platform, while maintaining the same protocol stack functionality and features.

The RF transceiver completes the major components of the smart appliance platform, handling the duties of transmitting the packets over the air. The choice of RF transceiver together with the wireless protocol determines the environment in which the smart appliance can operate. If a low-power application requires wireless communication through obstructions such as walls, then a Sub-GHz transceiver may be more suitable. By contrast, higher-frequency bands such as 2.4 GHz make for a better choice in applications requiring higher data throughput.

Traditionally, RF transceiver design is a very complex undertaking. To help alleviate this complexity, manufacturers have designed fully integrated and FCC/ETSI certified RF modules, such as Microchip's MRF24WB0MA embedded Wi-Fi module. These modules include the RF transceiver, the functional antenna and the supporting RF circuitry. Appliance manufacturers may simply include these modules in their designs, rather than acquiring the RF expertise to design the transceiver from the bottom up. Using modules reduces the time-to-market, risk and development costs.

There is a strong interdependency between all three components of the platform. OEMs such as Microchip have recognized this interdependency and have developed complete platforms that are suitable for smart appliance development. For example, Microchip's wireless development environment includes support for any combination of its 8-, 16- or 32-bit microcontrollers with sufficient MIPS and memory; RF transceivers both in the 2.4 GHz and Sub-GHz spectrums; and multiple wireless protocols, including Wi-Fi, ZigBee, RF4CE and MiWi proprietary.

Design considerations

A common pitfall that designers encounter as they develop a wirelessly enabled smart appliance is the failure to future-proof their devices. For example, choosing a wireless technology that cannot be scaled upward to accommodate the demand for the larger networks of the future is a problem. One design consideration is that even though these smart appliances are packed with the latest technology, their interfaces should be clean, intuitive and simple for the user, or else these appliances may not gain wide acceptance in the marketplace.

Often, designers fail to take into account both the physical and RF environments in which their smart appliances will reside. Therefore, factors such as humidity, the thickness of walls, and the presence of microwaves must be considered when designing the device. The styling of an appliance and its functionality should be cohesive, such that the former does not degrade the latter.

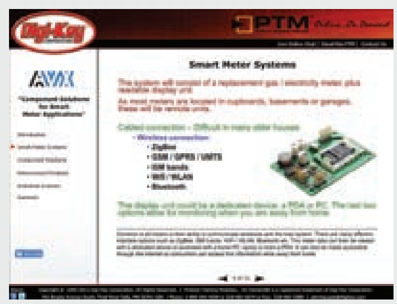
Consideration should also be given to the appliances' certification, particularly for those that employ open-standard protocols. The product's certification is a key milestone that must be completed before the product can be sold.

Conclusion

In this article, the major components that make up a wirelessly enabled smart appliance platform were described. These components are the microcontroller, the protocol stack, and the RF transceiver. Innovations in each of these subsystems have enabled smart appliance manufacturers to integrate wireless communications capabilities into their products. Along with these innovations come design challenges, such as choosing the appropriate encryption algorithm and ensuring that the wireless networks in which these devices operate can be scaled upward as demand for the devices grow. Both consumers and manufacturers stand to benefit from these new wirelessly enabled smart appliances, as entities such as utility companies offer useful, cost-saving products and services based on these devices. The Google PowerMeter and load-control services are two such examples, with many more such services becoming available every day.

Component Solutions for Smart Meter Applications

AVX Corporation



AVX's guide to component solutions for smart meter applications reviews the need to upgrade power grids with smart metering technology. It also presents a high-level overview of smart meter systems and explains how AVX products can support engineers in this process.

The guide features figures depicting how AVX component solutions can work for household systems and industrial systems, and detailed photographs and descriptions of smart meter interconnect products that allow for communication of data to data center.

The guide is 21 pages in length and can be viewed with or without audio in approximately ten minutes.

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A Simple, Cost-Effective Approach to Home Automation

by Emmanuel T. Nana, *NXP Semiconductors*

Homeowners have several energy management technologies to choose from, but the simplest, most cost-effective approach is to use the home's existing wiring to create the control network.

For most homeowners, nothing could be simpler or less expensive than using their home's existing wiring to create a control network. There's no need for extensive renovations or new wires for the control network, and there's no special hardware or software tools to install. For these reasons, powerline solutions are emerging as a popular approach for in-home energy monitoring and control.

Once the control system is in place, the homeowner gets to enjoy several benefits. The system can deliver considerable cost savings in terms of energy bills, with precise control of lights, fans, and home appliances, and by allowing appliances on the same network to share data communications. Plus, with a system that includes automated functions, events can be initiated and appliances can be turned on and off automatically, without user intervention. This lets homeowners take advantage of lower utility pricing during off hours, and gives greater control over the home environment when the homeowner isn't there. Lights can be programmed to turn on and off at specific times, and appliances can be configured to track their own operating data to monitor energy usage.

The TDA5051A from NXP Semiconductors, a highly integrated modem for in-home control applications, gives developers a simple, convenient way to meet consumer demands for low-cost, energy-saving networks for home automation. Optimized for Amplitude Shift Keying (ASK) data transmission and reception over a home power network, the TDA5051A can be used in a range of home-control applications, such as lighting, home appliances, energy monitors and meters, and heating and cooling systems.

NXP ASK powerline modem TDA5051A

The NXP TDA5051A transmits and receives digital signals on standard powerlines or any two-wire AC or DC network. It is a cost-effective solution that transmits at a rate of 600 (typ) or 1200 (max) baud, operates from a single +5 V DC supply, and enables easy connection to standard microcontrollers, including NXP's LPC11xx series of low-power ARM-based microcontrollers. The carrier frequency is set by an input reference clock or an on-chip oscillator.

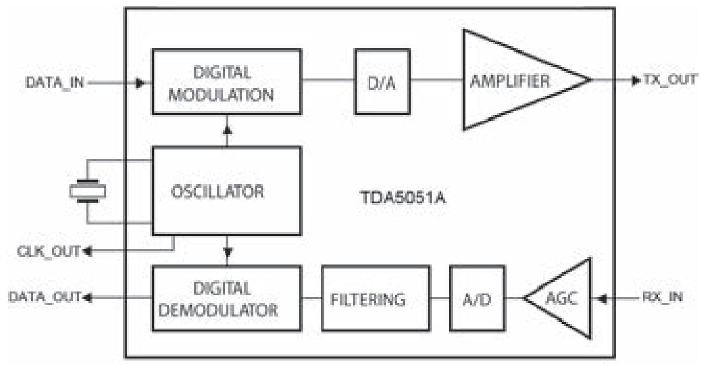

Figure 1: TDA5051A block diagram.

Figure 1 gives a block diagram of the TDA5051A circuit. The IC includes a high-sensitivity input amplifier with Automatic Gain Control (AGC) for secure detection of small signals on noisy mains. It also has a digital narrowband filter with an 8-bit ADC for accurate, sharp filtering of the incoming signals, and a variable-threshold digital demodulator for optimum recovery of the baseband data signal. The data pins are TTL/CMOS compatible for direct connection with a microcontroller, and the circuit supports operating frequencies from 95 to 148.5 kHz.

The IC is designed for worldwide use and complies with industry-standard regulations. It is compliant with US Federal Communication Commission (FCC), Industry Canada, Japan MPT, and European CENELEC EN50065-1 regulations for signaling in the 125 to 140 kHz and the 95 to 125 kHz frequency bands.

The transmission and reception stages are controlled either by an external reference clock, from the system's microcontroller, for example, or by the on-chip reference oscillator connected to a crystal. This ensures the accuracy of the transmission carrier and the exact trimming of the digital filter, thus making the performance independent of application disturbances such as component spread, temperature, and supply drift.

The device includes a power output stage that feeds a 120 dBμV (RMS) signal on a typical 30 Ω load. To reduce power consumption, the IC is disabled by a power-down (PD) input pin. In this mode, the on-chip oscillator remains active and the clock continues to be supplied at the CLK_OUT pin. For low-power operation in reception mode, this pin can be dynamically controlled by the microcontroller.

Table 1: TDA5051A highlights.

Features	Benefits
ASK powerline modem operating at up to 1200 bps.	Easy to implement, simple to modulate/demodulate and requires little bandwidth.
Carrier frequency set by clock from microcontroller or on-chip oscillator.	Flexibility in choosing clock source.
AGC receiver input.	Improved noise performance and adjustment of signal level. Ensures maximum sensitivity of ADC.
Easy compliance with EN50065-1 with simple powerline coupling networks.	Used with powerlines worldwide and complies with industry-standard regulations.
SO16 plastic package.	Low-cost solution with easy assembly.

Housed in an SO16 plastic package, the TDA5051A requires just a few external components for full operation. To complete a home automation application, a low-cost mains coupling network, a 5 V power supply, a microcontroller (which can use the same supply), and a standard quartz crystal, which is used with the on-chip clock circuit to set the modem's operating frequency, are required. For added simplicity, the CLK_OUT output signal can be used to clock the microcontroller.

Transmission, reception, and data formats

The TDA5051A has been optimized for performance in applications requiring data communication over any two-wire AC or DC network. During transmission, to provide strict stability with respect to environmental conditions, the carrier frequency is generated by dividing the reference clock by 64, using a prescaler divider in the device. High-frequency clocking rejects the aliasing components to such an extent that they are filtered by the coupling LC network and do not cause any significant disturbance. The data modulation is applied through the DATA_IN pin and smoothly applied by specific digital circuits to the carrier (shaping). Harmonic components are limited in this process, thus avoiding unacceptable disturbance of the transmission channel (according to CISPR16 and EN50065-1 recommendations). A -55 dB Total Harmonic Distortion (THD) is reached when the typical LC coupling network (or an equivalent filter) is used.

The DAC and the power stage are set in order to provide a maximum signal level of 122 dBµV (RMS) at the output. The output of the power stage (TX_OUT) must always be connected to a decoupling capacitor, because of a DC level of $0.5V_{DD}$ at this pin, which is present even when the device is not transmitting. This pin must also be protected against overvoltage and negative transient signals. The DC level of TX_OUT can be used to bias a unipolar transient suppressor. Direct connection to the mains is done through an LC network for low-cost applications. However, an HF signal transformer can be used when powerline isolation must be performed.

In reception mode, the input signal received by the modem is applied to a wide range input amplifier with AGC (-6 dB to +30 dB). This is basically to improve noise performance and adjust the signal level, so as to ensure maximum sensitivity in the ADC. An 8-bit conversion is then performed, followed by digital band-pass filtering, to meet the CISPR16 normalization and to comply with some additional limitations met in current applications. After digital demodulation, the baseband data signal is made available after pulse shaping. The RX_IN signal pin is a high-impedance input which has to be protected and DC decoupled for the same reasons as with TX_OUT pin. The high sensitivity (82 dBµV) of this input requires an efficient 50 Hz rejection filter (realized by the LC coupling network), which also acts as an anti-aliasing filter for the internal digital processing.

In transmission mode, the data input (DATA_IN) is active LOW: this means that a burst is generated on the line (TX_OUT pin) when the DATA_IN pin is LOW. The TX_OUT pin is in a high-impedance state as long as the device is not transmitting. Successive logic 1s are treated in a Non-Return-to-Zero (NRZ) mode. In reception mode, the data output (DATA_OUT) pin is active LOW; this means that the data output is LOW when a burst is received. The DATA_OUT pin remains LOW as long as a burst is received.

Powerline isolation

Since the TDA5051A connects to the powerline, it needs to be isolated from current spikes and noise. Figure 2 shows a schematic of the TDA5051A featuring powerline isolation. The IC has unique features for a digital powerline communication system. The powerline isolation circuitry and the receive/transmit (Rx/Tx) data interface to the powerline are provided by a specialized converter transformer. A series power inductor and a high-voltage coupling capacitor afford powerline filtering. The powerline isolation circuitry and the AC-to-DC power supply circuit provide the +5 V DC supply for the TDA5051A.

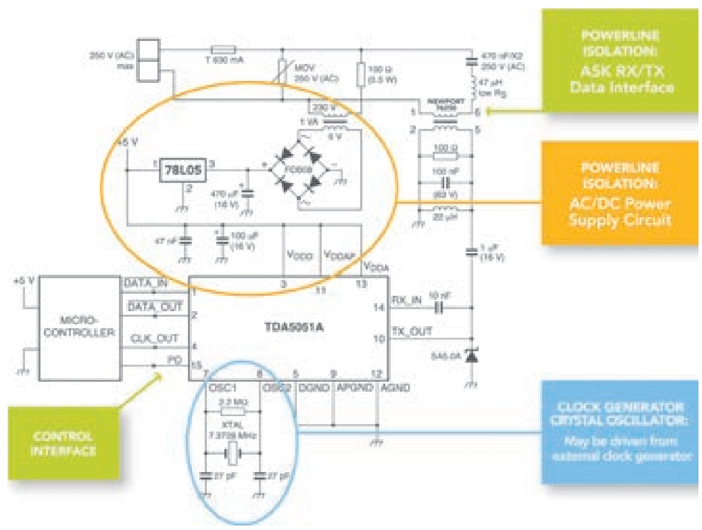

Figure 2: The TDA5051A with powerline isolation.

In the configuration shown, the reference clock is generated by a low-cost, fundamental crystal oscillator. The reference clock can also be provided by an external clock source, such as from the microcontroller clock, or the clock output (CLK_OUT) of the TDA5051A can be used as the clock for the microcontroller. The CLK_OUT, DATA_IN, DATA_OUT and PD (power-down) pins provide easy interface with the microcontroller.

ASK redundancy software protocol

ASK transmission is relatively inexpensive, easy to implement, simple to modulate/demodulate, and requires little bandwidth compared to other formats, such as Frequency Shift Keying (FSK). One drawback of ASK, however, is that it can be difficult to use in noisy environments.

To help address this, NXP has developed a special ASK protocol for use with the Cortex-M0 microcontroller LPC1114. The software provides robust control via powerline communication for home automation of lighting, appliances, and security systems. The protocol used for the ASK modem calculates and checks the parity on each byte and the checksum on each message. A slave that receives a proper framing byte, the correct number of bytes in the message, and no parity or checksum errors, will transmit a successful acknowledge message and act on the command embedded in the message. If the acknowledge message is not received within a preset time, the master re-transmits the message up to ten times until a successful acknowledge message is sent. The dedicated ASK protocol includes redundancy and improves the robustness of the TDA5051A, even in environments that are comparatively noisy.

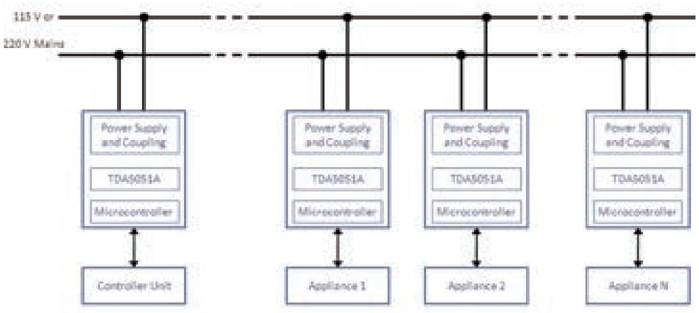

Figure 3: The TDA5051A in a home-control network.

Sample application: home-control network

Figure 3 shows the TDA5051A in a home-control network. The network includes a single control unit and several appliance units. The control unit sits on a 220 V powerline and is connected to appliance units located throughout the house. Each appliance unit is associated with an electrical appliance – a lamp, a fan, or a refrigerator – just about anything with an on/off switch can be put on the network.

The control unit includes a microcontroller, such as the LPC1114, and supports an interactive interface that the homeowner uses to configure and control the network. Each appliance unit is equipped with a low-cost microcontroller to process data received from and transmitted to the powerline.

The microcontroller in the control unit writes data to the TDA5051A. The TDA5051A encodes the data and sends it over the powerline. The TDA5051A in the appliance unit receives the data from the powerline and decodes it for the low-cost microcontroller, which uses the data to perform the function requested by the control unit.

This in-home control network is designed to support a wide variety of commands. In addition to simple on/off commands, it can support incremental commands such as bulb dimming or adjusting window blinds up or down. The network can control appliance operation, too, such as turning on a DVD player and then playing a DVD. The set-up can also transfer data across the network, to monitor energy usage or send notifications, such as when a refrigerator has been opened.

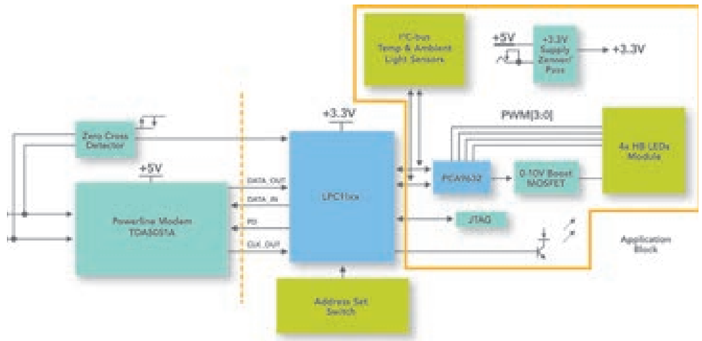

Figure 4: The TDA5051A in a lighting-control network (demonstration kit).

Sample application: lighting control

Figure 4 shows the TDA5051A modem and the LPC1114 microcontroller configured for a lighting-control application. NXP makes this configuration available in an evaluation/demonstration kit. The kit consists of a master controller and a slave lighting controller, each housed in a separate plastic box. The master controller consists of three boards: a TDA5051A board, an LPC1114 board, and a power-management demonstration board, which provides the +5 V DC and +3.3 V DC power supplies. The master controller board has four push-button switches to provide dim-up and dim-down, as well as on/off and color-mixing lighting control with a remote slave controller. Similar to the master controller, the slave controller also consists of three boards: a TDA5051A board, an LPC1114 board, and an LED driver/power supply board that controls a remote LED lighting array.

The slave controller is an addressable lighting controller capable of receiving commands over the powerline from the master control unit. The slave controller's command set includes functions such as on/off, brightness level, color mixing and luminary status. A high-brightness (HB) LED is used to indicate a slave fault. It blinks once a second to indicate normal operation. If the controller fails, it will not blink. An NXP PCA9632 is used for RGB color-mixing applications. The 4-bit, PWM0 to PMW3 outputs of the PCA9632 control the four HB LEDs and the 0 to 10 V Boost MOSFET. These outputs are compatible with applications relating to methods used by the lighting industry.

The demonstration kit uses a modular design that makes it easy to support other applications besides lighting. Simply replace the application block with circuitry for the target application; the TDA5051A and LPC1114 configurations remain the same. Other benefits of the kit include software support, zero cross detection, and redundancy support.

Summary

To meet the growing demand for cost-effective in-home control networks, NXP offers the TDA5051A, a highly integrated ASK modem that uses the existing mains network as the communication channel. Offering easy power isolation and supported by dedicated ASK protocol software, the TDA5051A delivers robust performance, even in noisy environments. When combined with the NXP Cortex-M0 microcontroller LPC1114, the TDA5051A enables a wide range of home-control applications. NXP supports the TDA5051A with a lighting-control demo kit that can easily be configured for other home-control applications.

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Emerson's KwiQMAte™ series designed for higher density packaging situations

Emerson Network Power Connectivity Solutions offers the Johnson product line of KwiQMAte connectors that feature a push-on style interface. Traditional SMA plugs need to be configured with extra space allowance for torque wrench coupling procedures. The KwiQMAte connectors are designed for higher density packaging situations with the push-pull connector interface allowing for more connectors per application.

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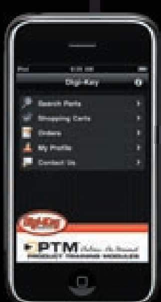

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Low-Frequency Radio in Active RFID Systems

by Ruggero Leoncavallo, *austriamicrosystems*

Recent enhancements in low-frequency receiver design reduce power consumption while improving receiver performance, promising to widen the range of applications in which active RFID systems can be implemented.

RFID (Radio Frequency Identification) is a popular technology in applications such as asset tracking and logistics support, and monitoring and access control, where they are sometimes also referred to as 'Real-Time Location Systems.' Up to now, most implementations of long range RFID have used an Ultra-High Frequency (UHF) reader operating in the 915 MHz frequency band combined with passive tags. Passive tags, which have no autonomous power source, generate their energy from the electromagnetic radiation emitted by the reader and communicate with the reader by changing their impedance (backscattering). As a result, passive tags have a limited range.

Some RFID systems, however, are required to operate in environments that are challenging to RF transmissions, such as in deep mines, inside metal shipping containers, and inside buildings with walls made of masonry. Achieving robust and reliable transmission with passive RFID systems is difficult when the radio signal must travel through obstructions such as rock, liquid, masonry, or metal.

For such applications, system developers must use an active RFID system, in which the tag includes its own battery power source. This enables the active transmission back to the reader of high-power UHF signals, which can consistently achieve a longer range than a passive tag can provide.

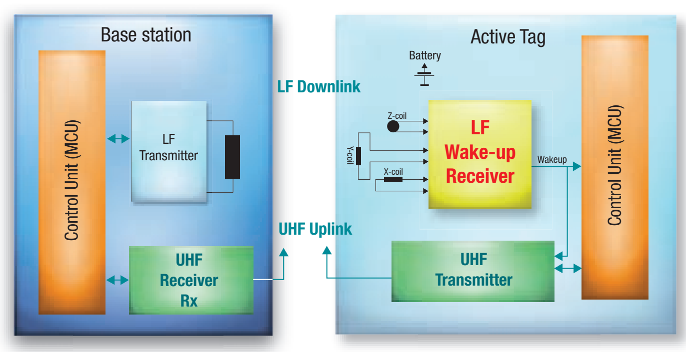


Figure 1: A system block diagram of an active tag.

A fundamental role in active RFID systems (Figure 1) is played by a low-frequency (LF) receiver which wakes up the system and triggers a UHF transmission. This article examines recent enhancements in LF receiver design that reduce power consumption while improving receiver performance, promising to widen the range of applications in which active RFID systems can be implemented.

The principal challenge for the designer of active RFID tags is achieving both very long battery life and long range – two requirements that at first sight seem to be in conflict with one another. At the same time, tags must fit a small form factor so achieving long battery life by use of a large battery is not a viable option.

These constraints explain why the system architecture shown in Figure 1 has evolved. The interrogator (base station) is made up of an LF transmitter and a UHF receiver, while the tag consists of an LF wake-up receiver and a UHF transmitter. The interrogator transmits periodically (typically once a second) an LF pattern. After the transmission, the UHF receiver is switched on to check for replies from tags. At the tag, only the wake-up receiver is active in normal operation; whenever the tag is within the interrogator's range, the receiver wakes up the UHF transmitter (uplink) on detection of a pattern that it recognizes. Only then does the UHF transmitter transmit the information required to unambiguously identify the tag to the interrogator. This architecture allows the UHF radio to stay in power-down mode almost continuously.

In terms of power, then, the LF receiver is the most important element, since it is the only element that must always remain active. Sensitivity is another key parameter of the LF receiver, as the signals in the target applications might be attenuated by distance and physical obstructions.

For active tags, the requirement for battery life is three years (minimum) from a simple coin battery such as a CR2032. This constraint implies that the tag's current consumption should be limited to little more than the battery leakage current while in receive mode. This in turn makes the choice of the operating frequency extremely important. To achieve the low power requirement, the receiver must operate at <300 kHz. RFID systems today typically use the 125 kHz or 134 kHz frequencies.

This, then generates the first challenge in the radio implementation: at such low frequencies the wavelength is large, requiring a correspondingly large antenna. Successful designs use loop antennas, which only sense magnetic fields (H). A loop antenna is essentially an

inductor made up of coils of ferrite rods. As Figure 2 shows, the LF transmitter in the base station and the LF receiver in the tag together work like a transformer, where the inductor at the transmitter is the primary coil and the one at the receiver is the secondary coil.

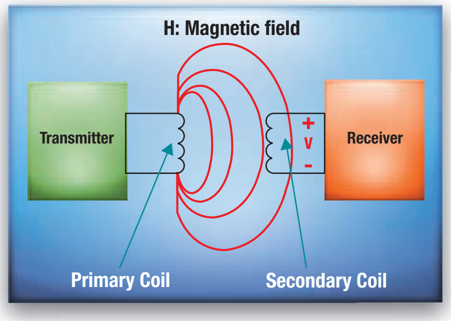


Figure 2: A transmission scheme using magnetic coupling.

In order to increase both the magnetic field generated by the transmitter and the voltage picked up by the receiver, both coils are tuned with capacitors in order to resonate at the carrier frequency. This resonator can be damped using a parallel resistor to increase the bandwidth of the antenna.

Effective tuning is one measure that increases the sensitivity of the LF receiver, but the use of loop antennas poses another problem. Since the antennas sense a magnetic field, the orientation between the base station (transmitter) and the receiver has an important effect. Electromagnetic theory dictates that if the two coils show a 90 degree phase shift in space (Figure 3), the induced voltage on the secondary coil is in theory zero.

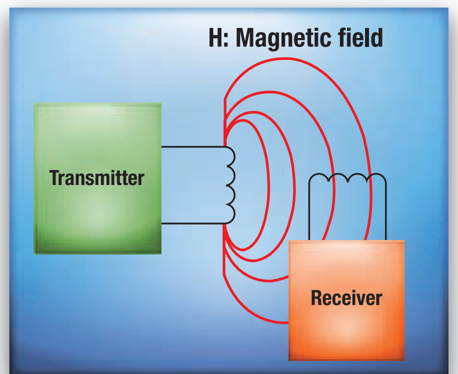


Figure 3: In magnetically-coupled systems, the induced voltage is zero when the Rx antenna is phase-shifted by 90 degrees.

In some precisely-controlled applications, the mutual orientation between the transmitter coil and the receiver will be fixed and predictable: here, effective communication is assured so long as this fixed position has the reader's antenna and tag's antenna parallel to one another during the reading phase. If the mutual orientation is not fixed and predictable, the receiver requires a three-dimensional antenna array comprised of three antennas orthogonal to each other (Figure 4).

The combination of carrier frequency tuning and three-dimensional antennas described here not only extends the receive range, it also allows the production of reliable Received Signal Strength Indicator (RSSI) measurements. RSSI information can be useful in some applications as it provides an estimate of the distance between the tag and the base station.

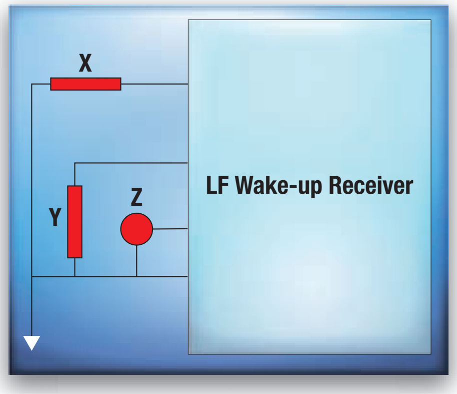


Figure 4: A three-dimensional orthogonal antenna array inside an active tag.

The architecture described above can reliably meet the required low average current draw, however, only on the assumption that the UHF transmitter is almost permanently in power-down. This means that the wake-up receiver must be able to reject false wake-up calls generated by noise or disturbance. Implementing a code or pattern-generation capability in the interrogator and a pattern-recognition capability in the receiver, solves this problem.

Active tag performance in practice

Typically active tags use single coin batteries of around 200 mAh capacity and the minimum expected lifetime is three years. This implies an average total current draw of approximately 7.6 µA. Assuming that on average half of the current is used by the UHF transmitter, the wake-up receiver can draw a maximum current of 3.8 µA.

The main constraint on the range of the system is the sensitivity of the wake-up receiver. A sophisticated LF wake-up receiver should offer sensitivity of at least 100 µV. Active tags offer very robust performance even in hostile environments: the low frequencies used can penetrate even extremely thick walls. The tag's UHF transmissions typically cover the required range even at output power as low as 0 dBm.

The latest approach to implementing LF wake-up receivers is exemplified by a device recently introduced by austriamicrosystems, the AS3933 LF wake-up receiver. On the crucial parameters, the AS3933 offers typical current draw in three-channel listening mode of 1.7 µA and typical wake-up sensitivity of 80 µVrms, which is more than ten times better than its nearest competitor. The wake-up interrupt can be triggered by frequency detection only, but to guarantee false wake-up rejection the device includes an integrated correlator that detects programmable 16- or 32-bit Manchester wake-up patterns.

Frequency tuning is an important technique for improving sensitivity and effective range; the AS3933 implements an automatic tuning function using on-chip tuning capacitors. This reduces bill-of-materials cost, since external high-precision tuning capacitors are not required, and it also enables simplified antenna-checking on the production line. Furthermore, the on-chip antenna tuning capability provides a means for end users to check the connection status between the tag and reader.

The FCC Road: Part 15 from Concept to Approval

contributed by Linx Technologies

Once your wireless widget is ready for market, how do you get FCC Part 15 approval? Knowing the process and starting it from the beginning helps shorten and smooth out the road ahead.

Many manufacturers have avoided making their products wireless because of uncertainty over the approval and certification process. While it is true that RF increases the effort and cost of bringing a product to market, it also can add significantly to the function and salability of a completed product. Thanks to a growing number of easily applied radio frequency (RF) devices such as those offered by Linx, manufacturers are now able to quickly and reliably add wireless functionality to their products. The issue of legal compliance for the finished product is straightforward when approached in logical steps.

Purpose of this article

This article gives a brief overview of the legal issues governing the manufacture and sale of RF products intended for unlicensed operation in the United States under CFR 47 Part 15. In the United States, the Federal Communications Commission (FCC) is responsible for the regulation of all RF devices. The FCC requires any device that radiates RF energy to be tested for compliance with FCC rules. These rules are contained in the Code of Federal Regulations (CFR), Title 47. Part 15 is the section of the code that deals with devices that emit RF energy and are to be operated without an individual license.

While this article will provide you with a basic understanding of the steps involved in certification, it is strongly recommended that you obtain a full copy of the code from your local government bookstore, the Government Printing office, or the FCC website.

What is "Unlicensed" operation?

Certain bands within the RF spectrum are available for "unlicensed" operation. The term "unlicensed" is often misunderstood. The manufacturer of a product designed for "unlicensed" operation is not exempt from testing and/or certification. Indeed, both the transmitter and receiver must be tested by a qualified testing laboratory. However, once the necessary approvals are received, the end user can then operate the product without further obligation or licensing.

Steps to Part 15 certification

Choose the optimum operating frequency

Part 15 governs a broad range of the radio spectrum ranging from below 1 MHz to in excess of 32 GHz. It is broken into individual sections that govern the use of specific frequencies and bands. For example, section 15.249 covers the 902-928 MHz band. In this frequency range a user is allowed to transmit any analog or digital signal they desire so long as the stipulations governing allowed output power, harmonics and occupied bandwidth are met. Other sections are not so accommodating. For example, in the 260-470 MHz band, the FCC considers not only RF factors but also the intended function and application.

In order to determine which operational frequency is best for your product, it is necessary to weigh both technical and legal issues. First, you will want to have a clear understanding of which frequencies are legally available, and then choose a specific frequency based on technical issues such as range, propagation, antenna length, power consumption and potential interference. (If you are not familiar with these technical issues, consult with a Linx application engineer or read Linx Application Notes focusing on those issues.)

Component selection

Once a frequency of operation has been selected, the RF section and antenna must be carefully designed and optimized to comply with the allowed power and harmonic limitations imposed by Part 15. This process is greatly simplified if you are using a Linx module, but it is still important to recognize that the antenna and layout play key roles in the product's legal operation.

Many modular RF transmitter products, including those manufactured by Linx, have the potential to output RF power in excess of Part 15 limits. This extra power helps designers overcome inefficient antenna styles and take advantage of the FCC's averaging allowance when modulation techniques such as ASK/OOK are employed. If necessary, output power may be reduced using the module's level adjust or an external attenuation pad.

Another consideration in antenna selection is that Part 15.203 requires the antenna to be permanently attached or coupled with a unique or proprietary connector. While this requirement leaves room for interpretation, the FCC's intention is that a user not be able to change the radiated characteristics of the device by easily interchanging the antenna with a higher performance model.

Build production-ready prototypes

After choosing a frequency for operation and a suitable RF stage, you will want to move from concept breadboard prototypes to a production-ready model as rapidly as possible.

Prescreen and optimize

Once a wireless product is finished, its output power and harmonics should be checked to ensure that the RF stage is both optimized and Part 15 compliant. This testing requires a spectrum analyzer and calibrated antennas. If you do not have access to these instruments, consider prescreening services such as those offered by Linx. The prescreening process can result in a cost savings over formal testing and provides an opportunity to maximize product performance.

Send the production-ready product to an FCC authorized testing facility

Once your product is in its finished form, exactly as it will be produced, testing should be conducted by a properly approved laboratory. In most cases, it is not necessary to be present for testing and the laboratory will prepare the filing paperwork.

The FCC has greatly streamlined the approval process by allowing independent laboratories to issue certifications though the Telecommunication Certification Body (TCB) program.

Unless specifically requested pursuant to Section 2.1076, receivers no longer require certification. They just require a quick test and issuance of a Declaration of Conformity (DoC) which should be maintained in the applicant's files. Transmitter certification is also relatively painless since many labs that are TCB certified are now allowed to issue certifications on behalf of the FCC. Full transmitter and receiver testing can cost around $5,000, transmitter only around $3,500, and the receiver about $1,500. The entire process can now be rapidly completed and many labs can perform other testing at the same time, such as Class A/B.

Label the product and market it

Following successful completion of the approval process, products should be labeled as required by Part 2.925 and 2.926 as well as Part 15.19 or otherwise prescribed by the FCC.

Summary

Bringing a product through the approval process (summarized in Figure 1) involves cost, effort, and in some cases frustration, but in the end your product will have an exciting new dimension of functionality and market appeal. By following the steps outlined in this application note and reviewing a copy of CFR 47 you will be well on your way to RF success. While complying with applicable provisions may seem unnecessarily restrictive, such regulations serve to ensure the availability of usable RF spectrum for every product.

The approval process

Introduction

Here in the United States the Federal Communications Commission (FCC) is responsible for the regulation of all RF devices. The FCC requires any device that radiates RF energy to be tested for compliance with FCC rules. These rules are contained in the Code of Federal Regulations (CFR), Title 47. The first volume of CFR 47 contains parts 0-19. The sections you will be dealing with throughout the approval process are primarily Part 2 and Part 15. Part 2 deals with issues of marking and authorization. Part 15 deals with the operational aspects and requirements for devices that emit RF energy and are to be operated without the end user needing a license. It is strongly recommended that you obtain a full copy of the code from your local government bookstore, the Government Printing office, or the FCC website.

Issues such as frequency selection, antenna compliance, and output power are covered elsewhere, therefore this section moves past those issues to the specific steps involved in the approval process.

Step one: lab selection

The FCC requires that final product testing be conducted by a registered testing facility. Labs that have indicated they are available to perform Part 15 testing for the public are listed on the Domestic Testing Facilities list.

The quality and competence of labs varies widely. Labs appearing on the list are independent. Linx is pleased to make recommendations of test facilities believed to be competent; however, it is the sole responsibility of applicants to select a test lab capable of measuring their specific device.

To pay or not to pay

Once you have chosen a lab, you must decide the extent of the services they will provide. Lab services range from basic testing, to full compliance testing and filing.

Our advice? Have the lab do as much as possible. Taking time to understand the subtleties of the filing process in the middle of trying to get a product to market is a bad idea. Saving a little money doing things yourself can end up costing far more than you save and in some cases might jeopardize your ability to receive approval.

Step two: registering

When your product is completed and ready for testing a Federal Registration Number (FRN) must be obtained. This is free and can be obtained online.

Next, request a grantee code from the FCC. This can also be done online.The grantee code costs $60 and must be paid within thirty days of the application. Form 159 is used for this and can be done online or printed and mailed.

Step three: testing

As previously mentioned, the FCC requires that final product testing be done in a registered test facility. Here, such items as output power, harmonics and spurious emissions will be tested. This facility will perform separate measurements on the transmitter and receiver as the transmitter and receiver require different types of authorizations from the FCC. The testing will usually take less than two weeks, but the actual time will depend on the test lab's backlog and schedule. It is a good idea to contact the lab well in advance to make them aware of your project and secure a spot in their testing schedule.

In order to have the best chance at approval it is important to explain the intended function of the product and any special operating characteristics to test lab personnel. If you are using a module that uses a keyed modulation method such as ASK/OOK, be sure your lab remembers to measure or calculate average power, not peak.

The test lab will require a number of items to complete the filing. These items will often include:

- A letter appointing the test lab as your technical agent for certification. The labs will provide a sample letter.
- The FCC ID Number of the unit. The first three digits are the grantee code obtained earlier. The last 14 digits are up to the applicant.
- A sketch of the location of the FCC label on your unit as well as a sketch (with dimensions) of the label itself.
- A block diagram of the unit showing all clock oscillators and their frequencies of operation. The signal path and frequency should be shown at each block.
- Full schematic diagram.
- The user's manual.
- A brief, non-technical description of the product and its operation.
- A product sample for testing and photos.

Transmitter testing

A product containing a Linx transmitter is considered by the FCC to be an intentional radiator because it intentionally emits RF energy into free space. Thus, it must be tested and certified before it may be marketed.

Certified transmitters are required to have two labels attached: an FCC ID label and a compliance label. The FCC ID label identifies the FCC equipment authorization file associated with the transmitter, while the compliance label indicates to the consumer that the transmitter may not cause, nor is it protected from, harmful interference. These labels may be combined for convenience.

Receiver declaration of conformity

A receiver is considered an unintentional radiator because, while not specifically designed to radiate RF energy, RF radiation may occur. For this reason the receiver must be tested and authorized by a Declaration of Conformity (DoC). In this simple process an accredited laboratory tests the product to ensure compliance with FCC standards. An FCC filing or submittal is not required unless specifically requested pursuant to Section 2.1076. The test results should be maintained within the applicant's files.

Conforming products are also required to have a compliance label attached to all items subsequently manufactured or marketed by the responsible party.

Filing confidentiality

Filing for confidentiality is an important and often overlooked issue. Unless otherwise requested the entire contents of your filing will become public information. You may request confidentiality pursuant to 47 CFR 0.459, which can prevent such proprietary items as schematic diagrams from falling into the hands of competitors. When confidentiality is requested, please label all items that are to be kept confidential from the general public "CONFIDENTIAL." Items that cannot be given confidentiality are: (1) photos of a device (anyone who purchases a device will know what it looks like), (2) test results (the public has a right to review a test report showing compliance with the FCC regulations) and (3) the user's manual. In general, the only information that is granted confidentiality is patented trade-secret information that if given out could harm a company financially.

Step four: The filing process

The FCC greatly streamlined the approval process. Certifications were once issued by the FCC directly, but independent testing laboratories are now allowed to issue certification though the Telecommunication Certification Body (TCB) program. They can also issue certifications for other countries with which the US has a Mutual Recognition Agreement (MRA). TCB's must be accredited and comply with Section 2.962.

The filing process is usually done by the test lab as a part of their service. The lab will compile the test report, photographs, and other items listed above. The TCB will review all application materials and, if the device conforms to the requirements, they will upload this information to the FCC. After the FCC receives the report they will add the product and the ID number to their database and their website and issue a Grant of Certification. At this point, the device can be legally marketed and sold. After certification, the FCC or the TCB may request a sample of the product to confirm ongoing FCC compliance.

Consideration for operation within the 260-470 MHz band

Introduction

This section is designed to give the reader a basic understanding of the legal and technical considerations for operation of RF devices in the 260-470 MHz band within the United States. The use of these frequency bands varies considerably worldwide, so it should be recognized that this application note is intended for designers utilizing Linx RF modules and planning to operate in the United States.

When working with RF, a clear distinction should always be made between what is technically possible and what is legally acceptable. Achieving a solution that meets technical objectives but cannot be legally sold or operated serves little use. As such, issues of legality should be given high priority.

Legal considerations

In the United States, the Federal Communications Commission (FCC) is responsible for the regulation of all RF devices. These regulations are contained in the Code of Federal Regulations (CFR), Title 47. Title 47 is made up of numerous volumes; however, all regulations applicable to operation in the 260-470 MHz band are contained in volume 0-19. It is strongly recommended that a copy be obtained and reviewed in its entirety. You can get a full copy of the code from your local government bookstore, the Government Printing office in Washington, or the FCC website.

What is unlicensed operation?

Certain bands within the RF spectrum are available for "unlicensed" operation. The term "unlicensed" is often misunderstood. The manufacturer of a product designed for "unlicensed" operation is not exempt from testing and/or certification. Indeed, both the transmitter and receiver must be tested by a qualified testing laboratory. However, once this has been done and any necessary approvals received, the end user of the product can then operate it without obtaining a license for its use.

Receiver procedure

The approval procedures for transmitters and receivers are quite different. The receiver is considered an unintentional radiator and is subject to authorization under the Declaration of Conformity process. This is a simple process in which an accredited laboratory tests the product to ensure that the equipment complies with FCC standards. The test results should be maintained within your files but an FCC filing or submittal is not required unless specifically requested pursuant to Section 2.1076.

Following successful completion of this process, the end product should be labeled as prescribed by the FCC.

Transmitter procedure

The transmitter is an intentional radiator and subject to certification. Certification testing should be performed by properly approved laboratory. In most cases you do not need to be present for testing and your chosen laboratory will prepare the filing paperwork. Certifications were once issued by the FCC directly, but now independent laboratories are allowed to issue certification though the Telecommunication Certification Body (TCB) program which has streamlined the process.

Following successful testing, a report will be produced showing information about the testing and your device. A label displaying your FCC ID number along with FCC prescribed information will need to be placed on your certified product.

The rules for transmitters operating in the 260-470 MHz band are governed by Part 15.231. In some bands the FCC specifies only fundamental power, harmonic levels, and allowed bandwidth. However, in the case of the 260-470 MHz band, the FCC also considers factors such as the intended application and transmission duration.

You will want to review the text of 15.231 in its entirety. When reviewing this section, it is critical to read paragraphs (A)-(D) as a unit, and recognize that paragraph (E) only applies if the rules of paragraph (A) cannot be met. Given the rules' complexity and application-dependent nature, they are best illustrated in Figure 1.

Functional Requirements

Once you are certain your application is allowed in principle, you will want to focus on understanding the specific functional requirements that must be met in order for your product to receive certification.

Determine and comply with allowed output power

Figure 2 shows the relationship between the fundamental frequency of operation and the allowed output power. Since the output power is allowed to climb as the frequency increases, it might appear that selecting the highest frequency would give the best range performance. This is not the case, however, since free space attenuation increases proportional to frequency. Thus, the regulations equalize the bands propagation characteristics. Antenna size and efficiency should also be considered. Compact or reduced sized antennas will generally not be as efficient at the lower parts of the band.

It is always important to note that the RF level radiated into free space is dependent not only on raw output power, but also factors such as the type of antenna employed, circuit layout and ground plane. Most transmitter modules, including those manufactured by Linx, are

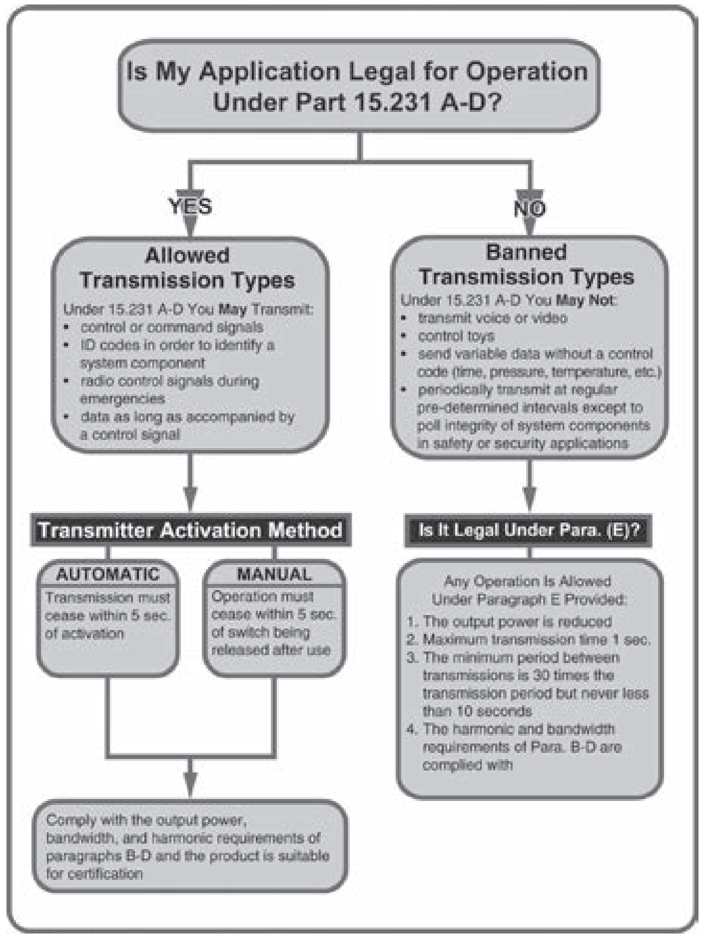


Figure 1: The Part 15 approval process.

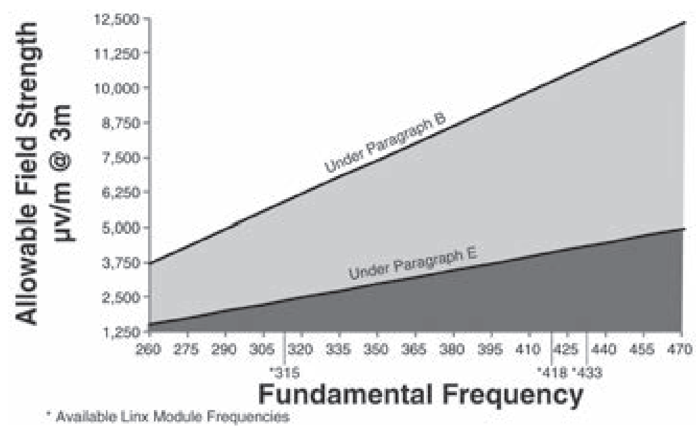


Figure 2: Frequency of operation versus output power.

capable of producing non-compliant output levels. This extra power helps designers overcome inefficient antenna styles and allows them to take advantage of the FCC's averaging allowance when modulation techniques such as ASK/OOK are employed. If the module is matched to an efficient antenna, the output power may need to be reduced using the module's level adjust or an external attenuation pad. For further details, review Linx Application Note #00150.

In addition to fundamental output power restrictions, the FCC also regulates allowed harmonic levels and occupied bandwidth.

Since this article is oriented toward users of Linx products, little detail is needed on these points as Linx modules are designed to meet these requirements. It is important, however, to note that there are ways in which a user can adversely affect harmonic content, including the use of a poorly matched or tuned antenna, supply/system noise, or layout or bypass issues.

While these considerations of legality may appear formidable, they generally are not. By choosing a correct operational frequency and using a pre-made RF module, a product designer's burden is greatly reduced. With proper attention to such basics as good layout, clean supply lines, and a properly matched antenna, RF success can be a nearly painless process.

Now that your application has hopefully survived the legal considerations outlined above, let's consider the actual technical issues of operation in these frequencies.

Benefits of operation in the 260-470 MHz band

First, it should be recognized that the unusual restrictions placed on the band by the FCC do more than just make a designer's life miserable. The random periodic nature of transmissions resulting from these restrictions helps to keep this set of frequencies clear of sustained interference. Other Part 15 bands are potentially crowded with continuous transmissions of voice, data, video, and even microwave ovens.

Second, longer transmission distances are achieved with less power. The free space propagation of frequencies in this range is significantly better than at higher frequencies such as 900 MHz or 2.4 GHz. Therefore, lower output power is needed to attain any particular distance and power consumption is significantly reduced.

Third is cost effectiveness. The components used at these frequencies are lower in cost than those designed for higher frequencies.

Fourth is international regulatory compatibility. If your product will be sold abroad, you will want to plan for international compatibility. Band allocation and regulations vary from country to country. For additional information you may wish to refer to Linx Application Note #129.

Common frequencies within the band and their uses

As you review Linx product offerings, you will notice three standard frequencies within the 260-470 MHz band. These frequencies are 315, 418, and 433.92 MHz.

- 315 MHz is commonly used for gate/garage door openers, security and keyless entry systems.
- 418 MHz is a very clean frequency here in the US and also appropriate for operation in Canada.
- 433.92 MHz is used throughout all of Europe. While it is allowable for use here in the US and Canada, interference from amateur radio, the nearby pager band and active RFID tags may sometimes pose a problem.

Summary

The 260-470 MHz band is ideal for transmitting control, command, or status signals. It should also be given consideration for control signals accompanied by data such as time, temperature, or pressure.

Considerations for operation within the 902-928 MHz band

Introduction

This section is designed to give the reader a basic understanding of the legal and technical considerations for operation of RF devices in the 902-928 MHz band. The use of these frequency bands varies considerably worldwide, so it should be recognized that this application note is intended for designers utilizing Linx RF modules and planning for operation within the United States.

When working with RF, a clear distinction should always be made between what is technically possible and what is legally acceptable. Achieving a solution that meets technical objectives but cannot be legally sold or operated serves little use. As such, issues of legality should be given high priority.

Legal considerations

In the United States, the Federal Communications Commission (FCC) is responsible for the regulation of all RF devices. These regulations are contained in the Code of Federal Regulations (CFR), Title 47. Title 47 is made up of numerous volumes; however, all regulations applicable to operation in the 902-928 MHz band are contained in volume 0-19. It is strongly recommended that a full copy of the code be obtained from your local government bookstore, the Government Printing office, or the FCC website.

What is unlicensed operation?

Certain bands within the RF spectrum are available for "unlicensed" operation. The term "unlicensed" is often misunderstood. The manufacturer of a product designed for "unlicensed" operation is not exempt from testing and/or certification. Indeed, both the transmitter and receiver must be tested by a qualified testing laboratory. However, once the necessary approvals are received, the end user can then operate the product without further obligation or licensing.

The frequencies from 902-928MHz are allocated for a wide variety of unlicensed applications. These include unlicensed products operating under Part 15 as well as Part 18 Industrial/Scientific/Medical (ISM) devices.

What must I do to be unlicensed?

Part 15 requirements for many bands are somewhat obscure and difficult to interpret. Thankfully, the regulations of Part 15 for the 902-928 MHz band are very straightforward. There are no restrictions on the application, content or duration of transmissions, only on factors such as power output, bandwidth, harmonic and spurious emissions.

While Linx modules are inherently designed to meet these requirements, it is important to note that external factors such as layout, antenna type, and output power can affect both the module's performance and compliance. While these issues may appear formidable, they are generally not. By choosing the correct operational frequency and using a pre-made RF module, a product designer's burden is greatly reduced. Since the approval procedures for transmitters and receivers are quite different, let's look at each separately.

Receiver procedure

The receiver is considered an unintentional radiator and is subject to authorization under the Declaration of Conformity process. This is a simple process in which an accredited laboratory tests the product to ensure that the equipment complies with all applicable FCC standards. An FCC filing or submittal is not required unless specifically requested pursuant to Section 2.1076. The test results should be maintained within the applicant's files.

Following successful completion of this process, the end product should be labelled as prescribed by the FCC.

Transmitter procedure

The transmitter is an intentional radiator and subject to certification. In most instances, users of modules manufactured by Linx will seek certification under part 15.247 for Spread Spectrum modules or under 15.249 for narrowband modules. An exception to this is RF modules which have been pre-certified by Linx under the modular approval process. In instances where certification is required, testing will need to be performed by a properly approved laboratory. In most cases it is not necessary to be present for testing and the laboratory will prepare the filing paperwork. Certifications were once issued by the FCC directly, but now independent laboratories are allowed to issue certification though the Telecommunication Certification Body (TCB) program which has greatly streamlined the process.

Following successful testing, a report will be produced showing information about the testing and the device. A label displaying the applicant's FCC ID number along with FCC prescribed information will need to be placed on the certified product.

Now that a basic overview of legal issues has been covered, it is time to consider the technical issues of operation in these frequencies.

Benefits of operation within the 902-928 MHz band

The first benefit of the 902-928 MHz band is freedom from the tight limitations and application restrictions the FCC places on some other bands. In this band virtually any analog or digital signal can be sent without restrictions on content or duration.

Second, higher legal output power allows the potential for much longer transmission distances.

Third, the propagation of frequencies in the 900 MHz range is better than at higher frequencies such as 2.4 GHz. Therefore, lower output power is needed to attain any particular distance, reducing transmitter power consumption.

Fourth is antenna size and compactness. A useful byproduct of higher frequency is shorter wavelength. This allows a 1/4-wave antenna in the 900 MHz range to typically be less than 3.25 inches in length. In fact, Linx's Antenna Factor division offers tiny surface mount antennas that are less than 0.65 inches in length, allowing for easy concealment in compact portable products.

Drawbacks to the 902-928 MHz band

The first drawback is the band's popularity (good in rock and roll, bad in RF). Products such as cordless phones have migrated to higher frequencies, but the growth of wireless and the benefits of the band make it likely to remain crowded.

Second is the potential for higher level interferers. In addition to its allocation for narrow-band devices, the 902-928 MHz frequency range is also allocated for higher power devices. While Linx employs a variety of techniques to minimize the possible impact of such interference, it should be considered.

Third is export. Allowed uses of the 900 MHz band vary outside the US and a products operation may not be legally allowable in other areas. Fortunately, nearby frequencies are standardized in the large European market. Linx offers a selection of footprint compatible products which accommodate domestic and export requirements with just a change of modules and antennas. For additional information you may wish to refer to Linx Application Note #129. Check the regulations for each country to which export is desired in order to assure the product will be legal.

Summary

The 902-928 MHz band is highly favorable due to minimal legal restrictions and excellent propagation characteristics. It is an ideal choice for analog or digital links, especially those that require reliability over long distances or which might be prohibited in other bands.

For additional information on FCC regulations you may wish to contact the FCC directly.

Federal Communications Commission
Office of Engineering and Technology
7435 Oakland Mills Road
Columbia, MD 21046
Phone: (301) 362-3000
Fax: (301) 344-2050
E-mail: labhelp@fcc.gov

You may also wish to visit the Linx Technologies website at www.linxtechnologies.com where a list of testing facilities and applicable sections of FCC regulations are available for review and download.

Frequently asked questions

How can I obtain more information on the approval process?

You may wish to obtain additional literature and application notes from Linx by visiting our website at www.linxtechnologies.com You may also visit the FCC's website at www.fcc.gov, email them at fccinfo@fcc.gov or call them at 1-888-CALL-FCC.

Where can I obtain a copy of the FCC Rules and Regulations?

The Rules and Regulations can be found online at:

http://www.fcc.gov/searchtools.html#rules

CFR Title 47, Parts 2 and 15 cover the use of Linx products. Excerpts from these parts are contained in this document. For a paper copy, you should go to the Government Printing Office's website at:

http://bookstore.gpo.gov/

and indicate that you need a copy of Title 47 of the Code of Federal Regulations (47CFR). If your need is for equipment authorization, you will require Volume 1, which contains Parts 0-19. Their telephone number is 866-512-1800 and email is ContactCenter@gpo.gov. You can also contact the Government Printing Office (GPO) in your local area for a copy of the rules. The telephone number for the GPO in your local area can be obtained from your telephone directory or operator, listed under the Federal Government.

I wish to locate a test laboratory in my area. Is there a list of laboratories in my area?

The FCC Laboratory makes available such a listing and it is updated monthly. This information is online.

How long will it take to receive an approval?

The testing will depend on the current backlog of the test facility that you choose. If your product passes the testing, the TCB will generally issue a Grant of Certification within a few days.

What does testing and certification cost?

This depends largely on the test lab and how many of their services you choose to utilize. Full transmitter and receiver testing can cost around $5,000, transmitter only around $3,500, and the receiver about $1,500. The entire process can now be rapidly completed and many labs can perform other testing at the same time.

What if my application is denied and I don't think the FCC correctly understood my product?

The FCC sees thousands of applications a year. Depending on your presentation, an inspector may misinterpret information. It is possible. If you feel you have fairly complied with the regulations, you will want to exercise your rights in accordance with CFR 47 2.923 and petition for reconsideration and review.

What happens if I change my design? Like a case, board or antenna?

For certified equipment (generally your transmitter), the holder of the grant of certification, or the holder's agent, can make minor modifications to the circuitry, appearance, or other design aspects of the transmitter. Minor modifications are divided into two categories: Class I Permissive Changes and Class II Permissive Changes. Major changes are not permitted.

Minor changes that do not increase the radio frequency emissions from the transmitter do not require the grantee to file any information with the FCC. These are called Class I Permissive Changes. (Note: if a Class I Permissive Change causes your product to look different from the one that was certified, it is strongly suggested that photos of the modified transmitter be filed with the FCC.)

Minor changes that increase the radio frequency emissions from the transmitter require the grantee to file complete information about the change along with results of tests showing that the equipment continues to comply with FCC technical standards. In this case, the modified equipment may not be marketed under the existing grant of certification prior to acknowledgement by the Commission that the change is acceptable. These are called Class II Permissive Changes.

Major changes require that a new grant be obtained by submitting a new application with complete test results. Some examples of major changes include changes to the basic frequency determining and stabilizing circuitry; changes to the frequency multiplication stages or basic modulator circuit; and major changes to the size, shape or shielding properties of the case.

No changes are permitted to certified equipment by anyone other than the grantee or the grantee's designated agent except that changes to the FCC ID without any other changes to the equipment may be performed by anyone.

The receiver is covered by a Declaration of Conformity (DoC), which states that the product was tested by the Grantee and found to comply with the applicable technical standards. The test data should be kept on file by the responsible party as defined in CFR 47 2.209, but nothing is actually filed with the FCC. This means that you will just need to have data on your product on file that shows that the modified product still complies with the regulations. Nothing needs to be filed with the FCC for changes in products covered by a DoC.

Where can I look up information on equipment if I know the FCC ID number?

The FCC maintains a database that can be searched on the Internet. The database contains information on all equipment that was granted through the Equipment Authorization process.

What happens if one sells or uses non-compliant low-power transmitters?

Bad idea. The FCC rules are designed to control the marketing of low-power transmitters and, to a lesser extent, their use. The act of selling or leasing, offering to sell or lease, or importing a low-power transmitter that has not gone through the appropriate FCC equipment authorization procedure is a violation of the Commission's rules and federal law. Violators may be subject to an enforcement action by the Commission's Field Operations Bureau that could result in:

- Forfeiture of all non-compliant equipment.
- A $100,000/$200,000 criminal penalty for an individual or organization.
- A criminal fine totaling twice the gross gain obtained from sales of the non-compliant equipment.
- An administrative fine totaling $10,000/day per violation, up to a maximum of $75,000.

What if my intended use or application does not seem to have been clearly addressed by the FCC?

Recognizing that new uses of low-power transmitters often generate questions that are not directly addressed in the regulations, the FCC generally welcomes inquiries or requests for specific interpretations. Occasionally, the FCC proposes changes to its regulations, generally to address industry concerns and/or as new uses of low-power transmission equipment appear. Any questions can be directed to the FCC at fccinfo@fcc.gov or 1-888-CALL-FCC.

How close to the products tested are production units required to be?

In the FCC's own word: identical. However, "identical" is further defined as identical within the variations that can be expected to arise as a result of quantity-production techniques. One of the advantages of using Linx modules is the tight production control and testing procedures to which the modules are subjected. Similar controls over the rest of your product's production will make compliance with these requirements straightforward.

Does the receiver need to be certified?

The receivers must be issued a Declaration of Conformity (DoC) by an accredited test lab. This is far less complicated and expensive than a transmitter certification. There is not an actual filing with the FCC. Just keep these documents in your company files.

This document is not endorsed nor approved by the FCC and no affiliation between Linx and the FCC is meant to be inferred.

Bluetooth Low Energy for Wireless Sensors and Actuators

by Rolf Nilsson, *connectBlue*

There are many wireless protocol options for low-power wireless sensor networks, but none are better suited to the task than Bluetooth low energy.

Wireless solutions are used in a variety of demanding industrial applications. Technologies such as Wireless LAN, Classic Bluetooth, IEEE 802.15.4/ZigBee, and Wireless HART all provide specific characteristics and are therefore suitable for different applications and specific demands. However, none of these technologies offer an optimal solution for a wireless connection for sensors and actuators in manufacturing automation. In these types of applications, the existing technologies are too expensive, too slow, or consume too much energy. The solution lacks a fast, robust, low energy transmission for wireless sensors and actuators. This is where Bluetooth low energy technology comes into play.

Table 1: A comparison of Bluetooth low energy wireless technology and other wireless technologies used in the manufacturing industry.

Parameter	Bluetooth	Wireless LAN	ZigBee/IEEE 802.15.4	Bluetooth low energy
Data Throughput	Moderate	Very Good	Not so Good	Not so Good
Robustness	Very Good	Moderate	Moderate	Very Good
Range	50-1000 m	50-300 m	75 m + mesh	10-300 m
Local system density	Very Good	Not so Good	Moderate	Very Good
Roaming	Moderate	Very Good	Not so Good	Moderate
Large scale network	Not so Good	Moderate	Very Good	Very Good
Low latency	Very Good	Moderate	Not so Good	Very Good
Pairing speed	Not so Good	Moderate	Good	Very Good
Power consumption	Good	Not so Good	Very Good	Very Good
Cost	Good	Not so Good	Good	Very Good

Bluetooth low energy technology, formerly known as Wibree, was originally developed for the high volume consumer market. Back in June 2007, Nokia and the Bluetooth SIG announced that Wibree would be integrated with Bluetooth. In June 2010, Bluetooth Core Specification v4.0 with the hallmark feature of low energy technology was published. Bluetooth technology now encompasses low energy (Bluetooth v4.0), Classic Bluetooth and high speed (Bluetooth 3.0 + HS).

Is Bluetooth low energy technology a new technology?

The answer to that question is that the technology is new in some aspects, but not in others. For instance, Bluetooth low energy technology is new in having an efficient discovery and connection setup, very short packets, asymmetrical design for small peripheral devices, and a client- server architecture. But there are also other aspects that are already well established through Classic Bluetooth, such as the Bluetooth radio, HCI logic and physical transport layers, and L2CAP packets.

Thanks to Bluetooth low energy technology, the way we have come to experience wireless is changing. Bluetooth low energy technology brings to the scene the possibility to use wireless in very simple and inexpensive devices, such as the case when integrating sensors. According to the Bluetooth SIG we are looking at potential billions in volumes in the following applications:

- Phone Accessories: > 10 billion
- Smart Energy (energy counter and displays): ~ 1 billion
- Home Automation: > 5 billion
- Health, Wellness, Sports and Fitness: > 10 billion
- Assisted Living: > 5 billion
- Animal Tagging: ~ billion
- P2P Intelligent Transport Systems: > 1 billion
- Industrial Automation/M2M: 10 billion

These high volumes and the possibility of integration in mobile phones and laptops allow for low-cost and long-term availability of the radio components.

The technology concept

Possibility for low-power consumption

Bluetooth low energy technology has been designed, from the beginning, to use the lowest possible power consumption. For instance, the Bluetooth low energy unit can be put in sleep mode where it is only used at an event of sending active files to a gateway, PC or mobile phone. Further, the maximum/peak power consumption is set to less than 15 mA and the average power consumption is at about 1 µA. A foundation for the low energy consumption is the very fast connection set-up (few ms) and the short messages. Therefore, the energy consumption is reduced to a tenth of a Classic Bluetooth

unit. In other words, a small coin cell – such as a CR2032 – is enough for 5-10 years of operation.

Cost and backwards compatible

In order to be backwards compatible with Classic Bluetooth and to be able to offer an affordable solution for very inexpensive devices, the chipset is available in the following two versions (Figure 1):

- Dual-mode: Bluetooth low energy technology as well as Classic Bluetooth functionality
- Stand-alone: Bluetooth low energy technology only in order to optimize cost, power consumption, and size which are particularly useful for small battery powered devices

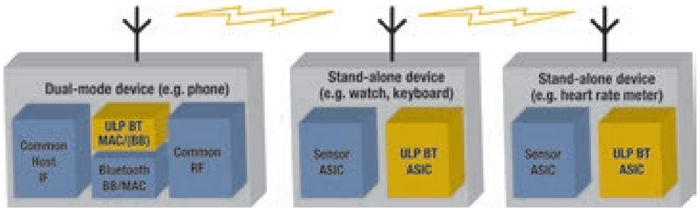


Figure 1: Bluetooth low energy chipsets are available in two versions.

Robustness, security and reliability

Bluetooth low energy technology, like Classic Bluetooth, features adaptive frequency hopping in order to secure a robust transmission even in harsh industrial environments. To obtain simpler and cheaper radio chipsets, Bluetooth low energy technology uses only 40 channels, 2 MHz wide while Classic Bluetooth uses 79 channels, 1 MHz wide. (Figure 2).

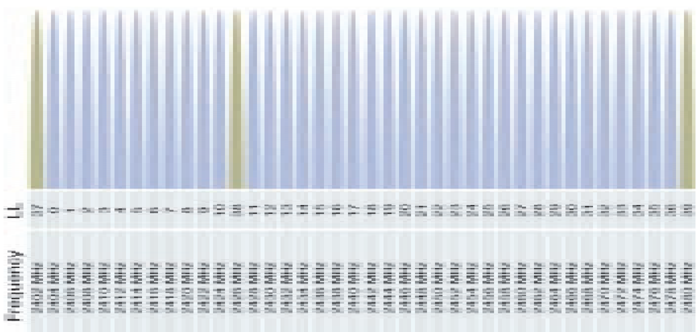


Figure 2: In the 2.4 GHz band, Bluetooth low energy technology uses 40 channels instead of the 79 channels used in Classic Bluetooth.

Three channels, which are located exactly between the Wireless LAN channels, are used for device discovery and connection setup.

Bluetooth low energy technology has a very secure AES 128 encryption algorithm, and a distributed encryption key procedure.

Coexistence

Bluetooth, Wireless LAN, IEEE 802.15.4/ZigBee, Wireless HART, and many proprietary radios use the unlicensed 2.4 GHz ISM (Industrial Scientific Medical) band. Therefore, in order to get a robust and reliable communication, it is essential for many wireless technologies to make a time consuming and accurate frequency planning. However, Bluetooth technology has already solved these issues thanks to its built-in adaptive frequency hopping feature and high tolerance for interference.

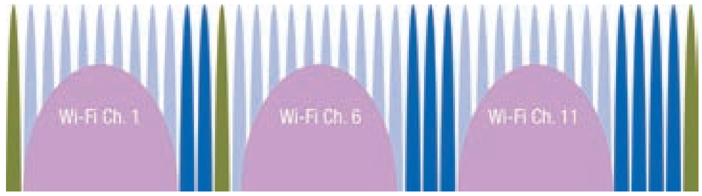


Figure 3: Out of the three advertising channels and the 37 data channels, the three advertising and nine of the data channels are located between the three Wireless LAN channels in the 2.4 GHz band.

These features also make Bluetooth low energy technology coexist smoothly with other wireless technologies in the 2.4 GHz band as Bluetooth technology does not use frequencies that are occupied by other radios in the neighborhood. In addition, there is also a possibility to apply the principle of not using designated channels via the so-called channel blacklisting (Figure 3).

Ease of use and integration

The technology uses a simple star topology, which simplifies the implementation work significantly. This topology fits very well with common used system architecture with a number of smaller devices connected to a master in a production island. In most cases, an Infrastructure/Ethernet network is available and there is no need for mesh networks to extend the geographical coverage.

A unit is always either a master or a slave, but never both. The master communicates with the slaves and it can also communicate simultaneously with multiple slaves. Further, the master controls the timing pattern for the links and the slaves only passes on requests made by the master. A new feature introduced with Bluetooth low energy technology is the advertising function. A unit announces itself by periodically advertising itself. An advertisement can also, for example, include a process value or an event that has occurred (Figure 4).

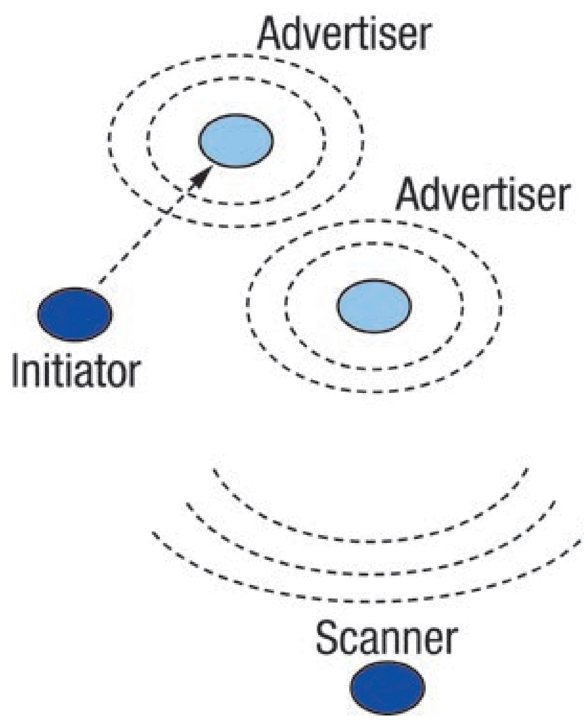


Figure 4: An advertiser periodically sends and will always act as a slave when it is connecting. A scanner is waiting for an advertisement and is always a master when connecting.

Software structure
In Bluetooth low energy technology, the state and attributes are key terms. All parameters have a condition available that is provided by the server in a protocol attribute for the client. All attributes have a certain characteristic – signal value, presentation format, etc. – which is described in the client configuration.

In the Generic Attribute Profile (GATT) service groups, attributes, declarations and descriptions are included. In the Generic Access Profile connection, discoverability, connectable and bonding are described. In this way, a number of basic services and profiles are set up such as for instance timing, battery condition, automation I/O, building automation (temperatures, thermostat, humidity), lighting (On/Off Switch, Dimmer), remote control, fitness (Step Counter, Heart Beat Monitor), medical devices (glucose meters), cars, etc.

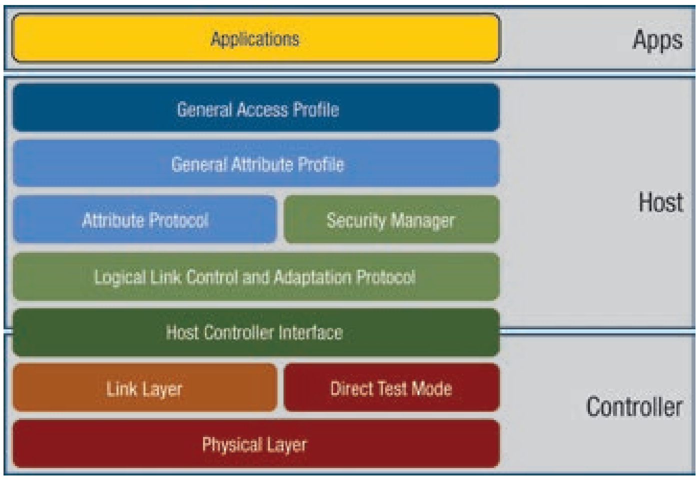


Figure 5: Overview of the Bluetooth low energy software structure.

Performance

Connection and latency
Bluetooth low energy technology only uses three channels to build connections and to discover other devices; this not only allows for lower power consumption, but also for a faster connection in only a few ms.

With Bluetooth low energy technology, the latency periods are dependent on how often the master sends messages to the slaves and how often it receives data from the slaves. The latency period for one slave only is 7.5 ms and then increases slowly for each additional slave. For example, with a connection interval of four seconds, a master can address one slave every five ms and thereby achieve updates from hundreds of slaves in only four seconds.

Range
Thanks to a modified modulation, Bluetooth low energy has an approximately 3 dB better link budget compared to Classic Bluetooth. A Bluetooth low energy unit can thereby offer a range of 200-300 meters in line of site without the need of an additional power amplifier. Although industrial sensors and actuators often only need a range of only 20-50 meters, it is important in the aspects of robustness and reliability to have a large reserve in order to bridge temporary obstacles and interference.

Application examples
Based on Bluetooth low energy properties, the technology is very well suited for applications where transferring signal status is important. The examples below show how the I/Os in industrial automation can be used (Figures 6-8).

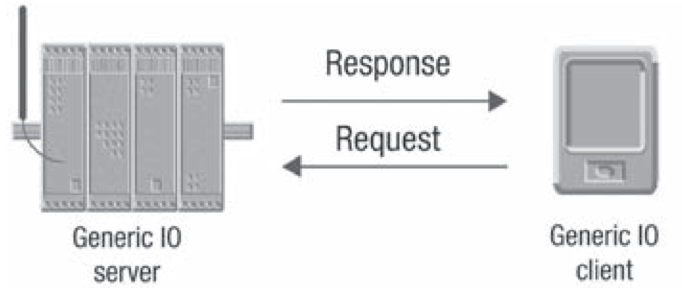


Figure 6: A portable operator control and monitoring unit (for example, an iPhone) can read and write states of the I/O server.

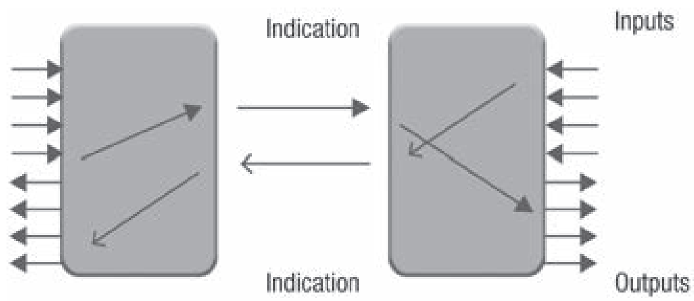


Figure 7: Both units function as generic I/O clients and are used as generic servers and "indications" to reflect the digital and analog states on the other side.

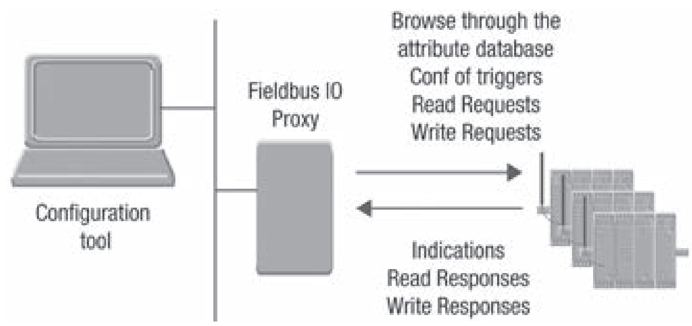


Figure 8: The I/O unit is a generic I/O server and the fieldbus I/O proxy is a generic I/O client. The I/O device is seen as a field bus I/O from the view of the fieldbus configuration PC. The field bus I/O proxy searches the I/O device attributes database to find out about which digital and analog in and outputs that are available for the I/O-unit.

Another interesting application where the very fast and secure connection is needed, is the use of Bluetooth Low Energy as a key in order to allow a mobile operator's panel to get access to the automation cell or machine.

This feature can also be used in combination with the proximity function. This function is based on the SSI (signal strength indication) value and can give a message if the user is within the production cell or not in order to allow interaction or not.

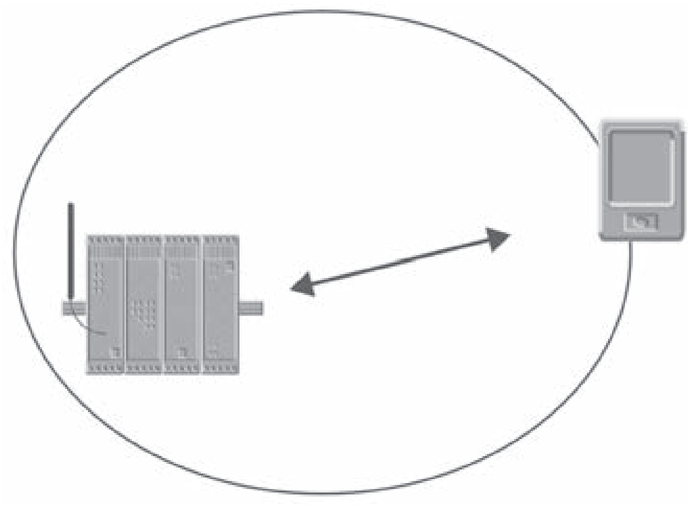


Figure 9: Automation I/O and proximity are used to control the operator's access to the manufacturing cell.

Conclusion

Bluetooth low energy technology meets all the requirements of a wireless solution for sensors and actuators. In short, the following are the highlights of Bluetooth low energy technology for sensors and actuators:

- Cost effective stand-alone solutions
- Multiple chipset supplier that secure a long-term availability of the components
- Robustness inherited from Classic Bluetooth - the most robust industrial wireless solution with more than 10 years experience
- Long range
- High local system density
- Very fast connection
- Low latency
- Simple star typology
- Low-power consumption
- Free-of-charge technical specifications
- Test support system through the Bluetooth SIG

Energy Harvesting for Wireless Sensor Networks

by John Bazinet and James Noon, *Linear Technology Corporation*

Wireless sensor networks require careful attention to power management if they are to meet their objectives in the field. Integrating energy harvesting techniques into your design can go a long way toward addressing the problem.

The increasing accessibility and performance of power miserly sensors, microcontrollers and RF transceivers is raising the potential for wireless sensor networks powered exclusively or supplemented by energy harvesting techniques. Ultra-low power wireless protocols are beginning to achieve widespread industry acceptance and standards are in active development. Sensor networks unshackled from the mains, or battery power, open the possibility for greater reliability, lower maintenance costs, improved safety and widespread deployment.

Applications unthinkable only a few years ago are now possible with energy harvesting techniques. Newly available power management products can convert the inconvenient, intermittent and often miniscule outputs of various energy harvesting transducers (Thermo-Electric Generators, photovoltaics, piezos, electromagnetics) into usable power for modern electronics. A new way of specifying, analyzing and designing with these power management devices is necessary to fully exploit the capabilities of the respective energy transducer elements and the sensor networks electronics that are ultimately powered by them.

Wireless sensors are not new, making them semi- or fully autonomous through the use of energy harvesting techniques requires the proper selection and design of energy transducers and power management devices. A typical wireless remote sensor node is shown in Figure 1. To date, the missing link in this system has been the power management solution. The transducers available to provide power are often very inconvenient to work with – producing a very low voltage, low impedance output or a very high voltage, high impedance output. The various elements in this system can be further broken down into power producers/regulators (transducer and power management) and power users (everything else). If the energy harvesting average output power capability exceeds the average power required by the remote sensor electronics, then you have the possibility for an autonomous system.

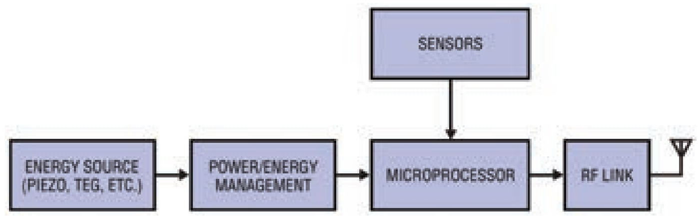


Figure 1: Typical Wireless Sensor System.

Before any design is initiated, it is worthwhile to run a quick feasibility analysis. This will quickly determine whether energy harvesting techniques are practical. The first step is to decide how often measurements need to be made and transmitted. We will call this measurement frequency (F). Next, we can determine how much processing power is required for the sensor, signal conditioning, data conversion and processing to generate the desired data, plus the RF transceiver power and time required to transmit this data.

Table 1 shows the typical power requirements for a popular microcontroller and RF link system. The power requirements can vary from manufacturer to manufacturer and for the particular application. There are many choices that can be optimized based on the end application. From this, we can calculate the system duty cycle and average power. The duty cycle (D) of the system is defined as: (Measurement time (T_m)+Processing time (T_p)+Transmit time (T_t)) x Measurement Frequency (F). The average power (P_a) is simply the total power (P) x D + the standby power, which is generally small enough to be ignored.

Table 1: Typical Power Requirements for Microcontroller and RF Link

	Processing Current/Sleep Current
Processor Power	3 mA/500 nA
RF Link	20-30 mA for 1-10 ms

Table 2: Typical Energy Sources and their Power Capabilities

Energy Harvesting Source	**Typical Power Range**	**K**
Solar (indoor/outdoor) single cell	10 µW-40 mW/cm^2	0.6-0.8
Vibration (piezo)	4 µW-100 µW/cm^2	0.8-0.9
Thermal (TEGs)	25 µW-10 mW/cm^2	0.3-0.5

For example, let's assume we are tasked with designing an autonomous indoor temperature sensor. This sensor will be deployed throughout a large office building and coupled with proximity sensors that can detect when a room is occupied and adjust the temperature accordingly. Deploying this type of sensor within a large building can reduce the annual heating and cooling costs significantly. The sensors require 500 μA at 3.3 V for 2 ms to measure temperature and detect an occupant. A low power microcontroller needs to operate on this data for another 5 ms. The microcontroller consumes 3 mA at 3.3 V, when processing the data. Finally, the RF link requires 30 mA at 3.3 V for 30 ms to transmit the data. The desired measurement frequency is 0.2 Hz (one measurement every five seconds).

$$D = (T_m + T_c + T_t) * F = (2\ ms + 5\ ms + 30\ ms) * 0.2\ Hz = \mathbf{0.0074}$$

$$Total\ Power\ (P) = (3.3\ V * .500\ \mu A) + (3.3\ V * .003) + (3.3\ V * .03) = \mathbf{110.6\ mW}$$

$$Average\ Power\ (P_a) = D * P = 0.0074 * 0.1106 = \mathbf{818\ \mu A}$$

Pa, or average power, is the key term that will tell us what types of energy harvesting transducers, if any, will be suitable for this system. Table 2 lists some typical energy transducers and the typical average power they are capable of delivering. The column labeled (K) is a power conversion constant that takes into account the type of power management block that is required to convert the transducer energy to a usable voltage, (3.3 V) in this case. A perfect power converter has a K=1. K will vary with the type of transducer employed. Generally speaking, K is proportional to the output voltage of the transducer. Since very low output voltage transducers like TEGs require an extremely high boost ratio and correspondingly high input currents, K tends to be lower than very high output voltage transducers like piezo elements. In the previous example, we can see that the average power required (P_a) is approaching the upper range of piezo transducers of a reasonable size, but is within the capabilities of TEGs and photovoltaic (PV) transducers or solar cells.

The system environment will usually dictate what type of transducer is selected. In our example, we cannot depend on an always-available light source, so PV transducers are not practical. We are at the upper end of what is feasible for piezo transducers, so we decided to use a TEG. TEGs utilize the Seebeck effect to generate a voltage across their output terminals when exposed to a temperature differential (see Figure 2).

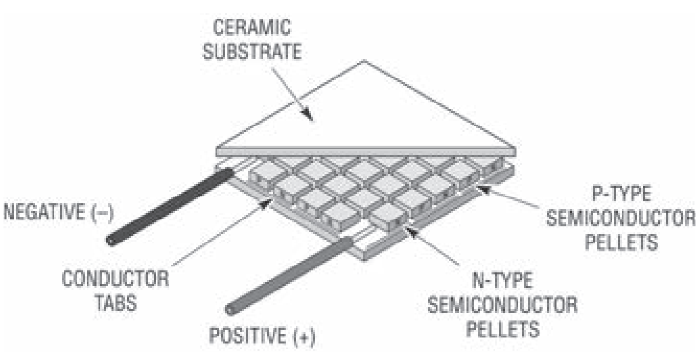


Figure 2: Typical TEG.

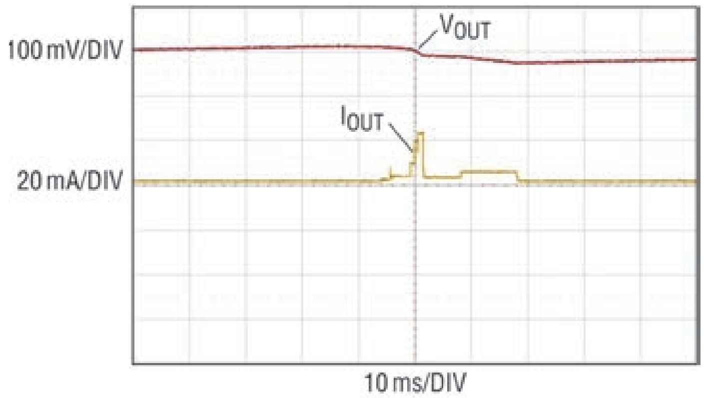


Figure 3: Typical Current pulse during measure and transmit cycle.

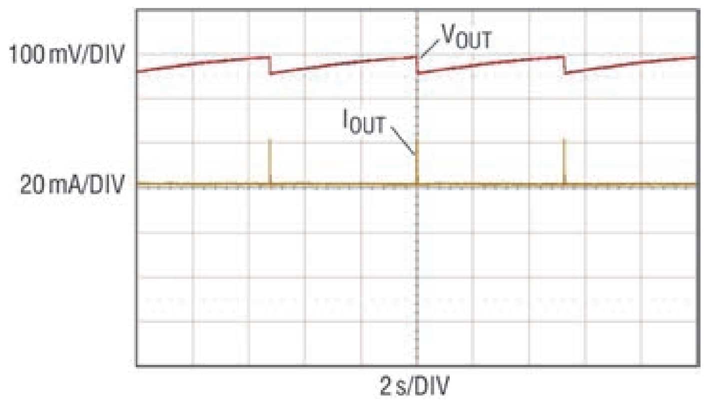


Figure 4: V_{OUT} ripple during measure and transmit cycles.

To further our example, let's assume that a 50 mm^2 TEG is selected. One side of the TEG will be mounted to the HVAC duct in the ceiling and the other side exposed to room temperature air. Since TEGs have a very low thermal resistance, it's often challenging to develop a suitable ΔT across them, so the room temperature side will employ a heat sink. Our measurements have shown that the HVAC duct surface will average 38°C in the winter (heating) and 12°C in the summer (cooling) with an average room temperature ambient of 25°C. Through careful measurements, we've determined that the ΔT across the TEG is ~+/-10°C when mounted to the duct with a heat sink. From the manufacturer's data sheet we can see that the TEG V_{OUT} with a 10°C dT is 180 mV. The TEG Output Resistance (R_{OUT}) is 2.5 Ω. The maximum power available to the load occurs when the TEG R_{OUT} = Power Converter (or load) R_{IN}.

If we assume that our power management circuit has a R_{IN} near 2.5 Ω, then the maximum power available to the power converter input is 180 mV^2/(2.5 Ω x 4) = 3.24 mW. Our power converter constant (K) is 0.4, so the total power available to the remote sensor 3.3 V output is 3.24 mW x 0.4 = 1.3 mW. Since 1.3 mW is comfortably above the previously calculated Pa of 818 μW, we can generate enough power to operate.

A power management circuit to convert the very low output voltage of the TEG to the required 3.3 V is the next challenge. A further complication is that the input voltage (TEG output) can be either positive or negative 180 mV, depending on whether the duct surface is hot or cold. While it may be possible to develop a discrete circuit to meet this challenge, it is often very difficult to achieve a solution that meets the system requirements for manufacturability, small size

and reliability. Further, circuit design is extremely sensitive to stray capacitance and the entire circuit needs to be micropower to achieve the rated K factor.

Fortunately, an integrated solution exists today. An example circuit using the LTC3109 is shown in Figure 5. The LTC3109 can operate from inputs as low as +/-30 mV and will produce any of four pre-programmed output voltages (V_{OUT}): (2.35, 3.3, 4.1 or 5 V). A switchable V_{OUT} is provided to power the sensors only when necessary. The LTC3109 also includes a power manager that is useful for storing and utilizing excess harvested energy. Since our typical load power is less than the available energy, any excess energy can be stored for later use on C_{STORE}.

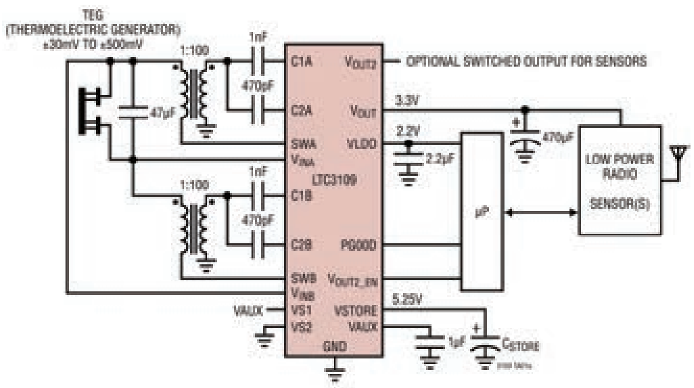


Figure 5: LTC3109 Power Management Circuitry.

Figures 3 and 4 show the 3.3 V output of the LTC3109 before, during and after a measurement/transmit cycle. The capacitor on V_{OUT} is sized based on the acceptable voltage droop for one measure/transmit cycle. In our example, we've determined that a voltage droop of 300 mV is acceptable on the 3.3 V output. Using the values obtained previously, we can calculate the required C_{OUT}:

$$C_{out} = \frac{(I_{load} - I_{avg}) * dT}{dV}$$

$$= \frac{(30\,mA * 30\,ms + 500\,\mu A * 2\,ms + 3\,mA * 5\,ms) - (\frac{1.3\,mW}{3.3\,V})}{0.3\,V}$$

$$= 1.74\,mF, select\ a\ nominal\ 2200\,\mu F\ capacitor$$

Where:

- I_{load} = sum of all the loads on the 3.3 V output
- I_{avg} = average output current of the LTC3109
- dT = duration of the load pulse
- dV = acceptable voltage droop

The actual droop in Figure 4 is much less than the 300 mV. This is due to a lower current transmit pulse duration for the simple system that was measured and the higher output capacitance.

Figure 6 shows the 3.3 V output during a temporary interruption of the energy harvesting transducer input. In this case the LTC3109 operates from the storage capacitor, C_{STORE}. There is no limitation on the value of C_{STORE}, so it can be sized for whatever system holdup time is desired.

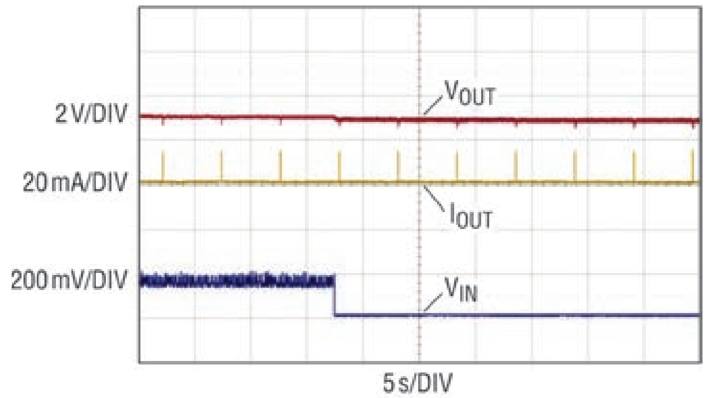


Figure 6: Operation during input source interruption.

The basic design procedure outlined above is applicable to other types of energy harvesting transducers. Power management circuits that interface with piezo elements (high voltage AC), electromagnetic (coil/magnet) and photovoltaic (solar cells) are all readily available today. In all cases, it is necessary to first determine the average load power required to see if autonomous operation is feasible.

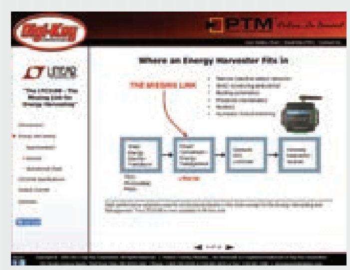
Summary

Average load power is the key variable to consider when contemplating the use of energy harvesting techniques to supplement or replace batteries in remote wireless sensor networks. The operating environment will always dictate what types of energy harvesting transducers are suitable and average load power will further narrow the choices. Power management solutions are now available to bridge the gap between low output power level transducers and ultra-low power microcontrollers, sensors and RF links. With all of the necessary elements in place, semi- or fully autonomous remote sensor networks have left the theoretical realm and are now poised to enter the mainstream.

The LTC3108 - The Missing Link for Energy Harvesting

Linear Technology Corporation

Linear Tech's LTC3108 is the missing link in energy harvesting. The Step-Up DC/DC regulator features a 20 mV resonant boost topology and an LTC-proprietary compound depletion mode. The circuit self oscillates and the built-in synchronous rectification improves energy harvesting yield.



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Is Minnesota Really That Cold in Winter? Find Out with Digi-Key's Weather Center

Have you ever wondered if winter temperatures in Minnesota really dip to negative 30 degrees Fahrenheit? Now you can find out by tracking Digi-Key's Weather Center without having to experience the bitter cold yourself. By the way, the answer is yes, it *is* that cold.

Engineers from Digi-Key's Design Support Services team began developing the Digi-Key Weather Center in a collaborative effort in February 2010. The Digi-Key Weather Center was placed on the roof of Digi-Key's 600,000 square-foot facility in Thief River Falls, Minnesota in July 2010. The Digi-Key Weather Center was developed to demonstrate connectivity to customers by using products sold and supported by Digi-Key. Because Digi-Key is located in Northern Minnesota where the weather changes dramatically from summer to winter, it was determined to be the perfect location to demonstrate data communication with a weather station.

The primary device used to develop the Digi-Key Weather Center was a ConnectPort X4 ZigBee to Ethernet gateway, which is equipped with access to iDigi from Digi International, one of Digi-Key's 440+ franchised suppliers. Additionally, Digi International Series 2 XBee modules programmed with ZigBee firmware were used for wireless communication to the device sensors and gateway. The initial sensor board was designed around a Microchip PIC18F14K22 microcontroller and a VTI temperature/pressure sensor, both of which are housed in a sealed Bud box with an IP65 rating. Solar panels from Parallax and sealed lead acid batteries from B.B. Battery and Panasonic were also used to develop the Digi-Key Weather Center.

Digi-Key Design Support Services team members Steve Dahl, Kevin Culkins, Shawn Rhen, Brandon Tougas, and Scott Raeker created the weather station, with each person assigned to different parts and stages of development. The project began with the design and construction of the structure that would hold the solar panel, control box and sensor nodes. Once the structure was completed, it was determined that sealed lead acid batteries and a charging circuit would be needed for power storage and distribution to the sensor nodes. The initial nodes developed for the project were a temperature/pressure sensor and a PWM controller enabled with a ZigBee module that relays the information to and from an Ethernet gateway. Next, python drivers were developed for the gateway, which relayed and managed the data to and from the sensor nodes. Finally, applications were developed for Android and Blackberry in order to present the data.

"Internet connectivity is quickly becoming more ubiquitous in our everyday lives. We wanted to develop an application that could illustrate functioning logic blocks to our end customers in multiple areas from self-sustained solar charging to remote communications with various sensors. All of the development is being shared in the public domain to jumpstart ideas or reduce our customers' development time. Given our remote location, having some fun with our extreme weather patterns seemed like a natural," said John LeDuc, Digi-Key's manager of Technical Content & Design Support Services. "Components from the semiconductor, interconnect, passive, and electromechanical product areas are used in this project to demonstrate the countless options engineers have when it comes to utilizing the products they have purchased from Digi-Key's expansive offering."

Recently, the Digi-Key Weather Center was updated with a "smart charger" (built with parts distributed by Digi-Key), which allows the Design Support Services team to control the charger and the loads that are attached to the weather station.

"The purpose of this project is to continually add to it," said Tougas. "We want to update the Digi-Key Weather Center with sensors as technology improves and show our customers a variety of ways to connect components and data over the internet."

This introduction marks the beginning of a series of articles dedicated to the development of the Digi-Key Weather Center. Additional articles focusing on the various components in the Digi-Key Weather Center and how they were implemented will appear in future issues of the Microcontroller, Sensors, Lighting, and Wireless Solutions *TechZone* Magazines.

Once the structure was assembled and powder-coated, the components were placed onto the structure. The first component was the solar panel (Parallax 750-00032-ND).

The main control box (Bud Industries 377-1139-ND), which houses the batteries and charge circuit, was mounted next.

In July 2010, the Digi-Key Weather Center was placed on the roof of Digi-Key's 600,000 square-foot facility in Thief River Falls, Minnesota.

The structure faces due south, the ideal direction to obtain the most solar exposure. The solar panel is connected to the main control box using weatherproof connectors.

Once the structure was securely anchored to the building, the charger and battery were added to the control box.

In November 2010, the Digi-Key Weather Center was updated with brackets to hold two more solar panels, making it possible to view most of the southern hemisphere to collect as much solar energy as possible. This is our version of solar tracking.

The battery charger board uses a Texas Instruments BQ2031 lead-acid fast-charge IC. Circuitry is based on TI's DV2031S2 lead-acid charger development board and configured for a 6-cell battery using the two-step voltage charging algorithm. Fast (bulk) charge voltage is set for 14.9 V and maintenance (float) voltage is set for 13.7 V. The input power for the charger is provided by the solar panel, which outputs approximately 20 V @ 0.5 A under full sunlight conditions.

Digi-Key's Weather Center

The Digi-Key Weather Center was developed to demonstrate connectivity to customers by using products available and supported by Digi-Key. Placed on the roof of Digi-Key's 600,000 square foot facility in Thief River Falls, Minnesota in July 2010, you can track the most dramatic of weather changes year-round. A collaborative effort by members of Digi-Key's Design Support Services team, find out more detail for yourself online at:

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Answers for TechZone Trivia crossword on page 31:
Across: 3 *minimized*; 5 *concerns*; 7 *legal*; 8 *socket*; 11 *three*; 12 *average*; 13 *MCUs*; Down: 1 *ZigBee*; 2 *technique*; 4 *Google*; 6 *meters*; 8 *Smart*; 9 *clearly*; 10 *mains*

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